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FIELD MAPPING *for* THE OIL GEOLOGIST

BY

C. A. WARNER

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BARTLESVILLE, OKLA.

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PREFACE

In the preparation of this work it has been the author's aim to furnish a hand book of field methods that would be of value to those geologists who have had little experience with the methods commonly used in examining a territory not yet drilled, a work which consumes much of the oil geologist's time.

To treat in a thorough way all the various subjects that might be considered under the head of Field Mapping would require considerable space; and in this hand book only the more important phases of Field Mapping have been considered. It has been the author's desire to give the reader a general knowledge of the more important principles and thus lay a general foundation upon which detailed work in any particular area can be carried further.

The work of the oil geologist is constantly expanding and his duties are no longer confined simply to the mapping of structures. He must be prepared to gather information after an area has begun to produce, as well as to keep in touch with all activities that bear upon the region in which he is working. For a knowledge of operations in a district, other than those of simple Field Mapping, the reader is referred to the book "Oil and Gas Production," by Johnson and Huntley.

The writer wishes to express his thanks to Professor H. Ries for helpful suggestions, to Professor G. D. Harris for the methods of meridian determination, and also to Dr. L. C. Snider, of the Empire Gas & Fuel Co., whose kind permission

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C. A. Warner.

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October 9, 1920

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FIELD MAPPING FOR THE OIL GEOLOGIST

CHAPTER I

STUDY OF FIELD CONDITIONS

Field Mapping, as the term is commonly used by oil geologists, may be taken to cover three distinct types of work, as follows:

I. A geologic examination of the area, including a consideration of all facts that bear upon the possibility of oil or gas occurring therein. Such an examination would deal with the age of the beds, their origin and structural features, and any surface indications of either oil or gas.

II. Mapping of the geologic structure, both of the formations exposed at the surface and of the producing sand or horizon, the latter of course being possible only when well records are available.

III. Plotting the results and preparing the report.

A Geologic Examination of the Area.—It is of course assumed that anyone intending to map possible oil- or gas-producing territory has, by reading at least, made himself familiar with the geology of these materials.[1]

[1] "Oil and Gas Production," by Johnson and Huntley.
"Popular Oil Geology," by Victor Zeigler.
"Practical Oil Geology," by Dorsey Hager.
"The American Petroleum Industry," by Bacon and Hamor.

PRELIMINARY OFFICE WORK.—Before undertaking the field study of any area it is, of course, important to make a thorough study of any and all available maps or reports which deal with the territory in question.

FIELD RECONNAISSANCE.—In the field a careful study should be made of all features that have any bearing on the occurrence of oil or gas, such as the age, character, and structure of the formations.

Age.—As explained below, there are certain rocks, such as the Pre-Cambrian, or even some of later age, which because of their nature are unfavorable for the formation, or accumulation, of either oil or gas. Other formations like those of Tertiary, Cretaceous, and Carboniferous[1] age have been found to be not unfavorable for the accumulation of these materials. This is doubtless true, since in the Tertiary, Cretaceous, and Carboniferous there were great quantities of organic matter, both animal and vegetable; and the hydrocarbons formed from this matter have accumulated in the rocks of the above formations—sometimes in porous sandstones, sometimes in other rocks, such as porous limestones, or dolomites. While rocks of other ages, as the Red Beds of the Permian, contain sand suitable for the accumulation of oil, yet they do not in themselves contain sufficient organic matter to permit the production of oil or gas in commercial quantities.

Kind of Rocks.—Since certain rock types are more favorable as oil and gas reservoirs than others, one of the first features to be considered in the area being examined is the kind of rocks present.

Igneous and metamorphic rocks contain little or no oil or gas, and hence such areas may usually be ruled out as nonproductive, the chief known apparent exceptions being those found in the Mexican oil fields, where petroliferous strata have been domed up around volcanic plugs, thus causing the oil to accumulate around these cores of igneous rock.

---

[1] This applies only to the West and is not true in all other cases.

Sedimentary beds containing insufficient amounts of organic remains to yield hydrocarbons in any considerable quantity may generally be rejected as unfavorable territory, although before any such area is ruled out as being probably non-productive, care should be taken to see that there is no possibility of oil or gas having migrated into these rocks from other sources. The geologist can sometimes determine the probability of such migration by a detailed study of the area in question and thus determine whether or not faults or unconformities are present which would bring a productive horizon in close contact with a non-productive one, and thus by migration of the oil or gas render the latter productive. This cannot always be done, however, as in some cases deposits of oil or gas are associated with faults and covered unconformably by non-petroliferous beds which obscure all evidence of such accumulations. Where faults appear at the surface, or where unconformities are found to exist, care should be taken to determine the magnitude of the former and also to know the age of rocks existing below those appearing at the surface, which might thus be brought in contact with the more recent formations. Thus, if it is found that the Pennsylvanian is overlain unconformably by younger formations suitable for the accumulation of oil or gas, and the Pennsylvanian has previously been shown to contain hydrocarbons in commercial quantities in that general region, then when a suitable surface structure is found above such unconformity it will generally prove productive when tested by the drill.[1] The same method of study may be used when faults are present.

---

[1] This appears to be the condition existing in certain or the fields of southern Oklahoma, especially those at Lawton, Loco, and to a lesser extent at Healdton.

Origin of the Sediments.—Sedimentary rocks may be deposited by wind or water.

Since but a small amount of organic matter could have accumulated in wind-formed beds, such formations will be productive of oil or gas only when these have migrated into them from other sources, and hence unless there is good evidence to this effect, aeolian rocks are not to be classed as favorable.

In water-laid deposits, especially those accumulated in shallow, quiet water, there is a much better chance for organic material to collect and for the consequent formation of hydrocarbons of commercial importance.

Proportion of Different Kinds of Sediments.—The relative abundance of sandstones, shales, and limestones and their relations to each other should also be considered.

The results of past experience in proven territory, especially in Oklahoma, Kansas, and Texas, indicate that in any considerable section of marine sediments, the prospects for oil and gas are better when there is a greater amount of shale in proportion to sandstone or limestone.

Thus assuming that the hydrocarbons originated in the shale, if there is a considerable thickness of sandstone, as compared to the former, the oil derived from the clay rock may be distributed through such a large mass of sand rock as to be of low concentration, unless gathered in a small area by the action of water; and even then the deposit would be small. On the other hand if the proportion of sandstone to shale is small, the hydrocarbons are concentrated in a much smaller volume of rock, other things being equal; and in addition the greater amount of shale present permits the formation of more oil and gas than would be possible were the shale percentage small.

The same condition also appears to hold true in the case of porous limestones associated with shale bodies.

Types of Structure Considered most Favorable.—Although oil and gas are associated with many different types of structure, those considered most favorable are anticlinal folds (usually associated with synclinal folds) and domes. Such types are found in the majority of the oil and gas fields of the United States, and may be classed as follows:

I. Anticlinal folds.
    a. Flat-topped, often canoe-shaped, and the closed folds being of more relative value than the open ones.
    b. Plunging anticlines.
    c. Terraces.
II. Domes or quaquaversal structures.
    a. Saline dome type.
    b. Volcanic necks.

While many other types of structure contain oil and gas in paying quantities they may in general be classed as variations of the above mentioned ones, with the possible exceptions of such occurrences as are found along sealed faults, in joint cracks, and at the contact of sedimentary and crystalline rocks. The latter types of occurrence are rare and are found chiefly in California and Canada.

Structural Conditions Affecting Accumulation of Oil or Gas.—Although the greater part of the oil produced in the United States is from some type of anticlinal structure, still not all such folds are productive of oil or gas, and it is therefore necessary that the geologist determine, so far as possible, the probability of production from a given structure. In doing this it is necessary to know, in advance of development, whether there are faults that have allowed the oil or gas to escape. If faults are found, the next step is to see if the oil has migrated to the surface along the fault-plane, and where such movement has taken place, to ascertain if a considerable amount appears to have escaped, or if the fault has been sealed up by early evaporation of the more volatile constituents. This can usually be done by a close study of the hydrocarbon deposits at or near the fault. Where a considerable amount of such deposit is present, as asphalt, gilsonite, or grahamite, it may be taken to indicate that the area is doubtless unfavorable for the production of oil or gas.[1]

When it has been determined that the fault, if any be present, is not of sufficient magnitude to have allowed any great quantities of oil or gas to escape, and that the structure warrants the expense of drilling a test well, care should then be paid to the log of the well and a close study made of the cuttings of the bit.

Where sands are found that appear favorable for the accumulation of oil or gas, in horizons which are known to be productive in adjacent localities, the presence or absence of water in that sand has a very important bearing upon future drilling. Since, theoretically, the oil, gas and water tend to arrange themselves with respect to their several gravities, it naturally follows that if water be found in the sand any probable production will be found up the dip—were the well drilled on the flank of the structure; while if no water is found the probable production will be found further down the dip. This rule is a general one and not true in every instance

Surface Indications.—While studying the structural conditions in the field, the presence of any oil seeps, asphaltic sands, or natural gas exhalations should be looked for.

Oil-Seeps.—Seepages of oil are sometimes found at the surface and often form a sort of scum on the surface of springs or pools of water, and at other times discolor the rocks. Not all iridescent scum on water, or discoloration of the rock, is due to oil, however; and it is frequently found desirable to test such so-called "shows" of oil. These seepages will often give a clue to a productive horizon which, though not productive at that particular area, may prove productive some distance away.

---

[1] The grahamite deposit at Ritchie Co., West Va., however, is at right angles to the direction of an anticlinal fold which is productive of oil, showing that in some cases not all the oil has been oxidized to grahamite.

When in doubt as to the origin of a scum over the water the simplest test is to break up the accumulation into small parts. If the scum is of an oily nature the edges of the smaller parts will tend to come together again in small masses with all edges rounded, while other accumulations do not possess this property, but rather remain in small angular particles.

To determine whether the discoloration of rocks is due to oil, or to stains of iron, the following test may be used: Pulverize some of the rock and dissolve—if possible—in a dilute hydrochloric acid solution and then add a drop of potassium sulphocyanate. If iron be present the solution will assume a deep-red color. Some of the solution shaken in a bottle containing carbon disulphide will show whether oil be present, for any that may be present will collect in the carbon disulphide and settle to the bottom of the container.

Many gas-seeps are caused by carbon dioxide and may be readily distinguished from natural gas in that they will not ignite when a lighted match is thrust into the escaping gas.

Summary of Geologic Reconnaissance Methods.—In general then, when examining an area for oil or gas resources, study and consider the following points with regard to the possibility of either of the above being present.

A. All available maps or reports which deal with the area.

B. The age of the beds, and conditions of life during that stage.

  1. Are the beds of such an age as to be of no value as reservoirs for oil and gas?

   2. Was there sufficient organic life during that stage to permit the formation of petroliferous deposits?
- *C*. Kind of rocks, whether igneous or sedimentary, and the possibility of oil having accumulated in those beds by migration from other horizons.
- *D*. Origin of the sediments.
   1. Wind-blown deposits may be considered unfavorable.
   2. If water-laid, were they deep or shallow water deposits? Were they affected by the action of currents? Was it possible for organic material to be laid down in those beds?
- *E*. Proportion of different types of sediments, especially with regard to the ratio of shale to other rocks.
- *F*. Structural conditions in the area, chiefly folds and faults.
- *G*. Surface indications of either oil or gas and determination of their real nature.

CHAPTER II

MAPS, THEIR VALUE AND INTERPRETATION

SINCE maps are so essential in the prospecting and development of oil and gas territory, the oil geologist should endeavor to obtain copies that are as accurate and detailed as possible. It may be well, therefore, to point out the kinds of maps that are available, and the sources from which these may be obtained.

Topographic Maps.—These usually show both the topography and cultural features. Such maps are prepared by the United States Geological Survey and are issued in sheets of convenient size, each representing a rectangular area called a quadrangle. The quadrangles mapped cover 1° of latitude by 1° of longitude, 30′ of latitude by 30′ of longitude, 15′ of latitude by 15′ of longitude, or smaller areas, the size of the map depending on the scale used. Topographic maps may be purchased from the Director of the United States Geological Survey at Washington, D. C., at 10 cents per copy in lots of less than 50 copies, or at 6 cents each in lots of 50 or more copies, whether of the same or different sheets; but since not all the areas have been mapped by the United States Geological Survey key sheets of the separate States have been prepared which show the areas mapped. These key sheets may be obtained free on application.

Each quadrangle has some distinctive name, such as that of the principal city, town, or some special feature shown on the sheet.

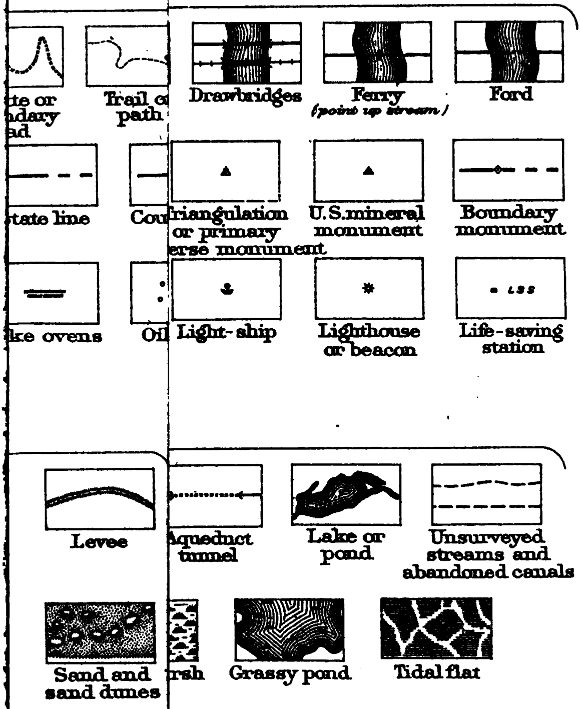
Since it is not possible to construct these maps on a scale that will even approach the size of the objects and features as they exist in the field, the Survey has selected several scales which are used for the different maps. These scales are represented on the separate sheets in the form of a fraction as, $\frac{1}{250,000}$, $\frac{1}{125,000}$, $\frac{1}{62,500}$, $\frac{1}{31,680}$. The smallest scale, that used for quadrangles covering 1°, is $\frac{1}{250,000}$ or very nearly 4 miles to the inch—that is, 4 linear miles on the ground is represented by 1 linear inch on the map. This scale is used for maps of the desert regions and some other parts of the far West. For the greater part of the country, which is mapped by quadrangles covering 30′, a larger scale, $\frac{1}{125,000}$, or approximately 2 miles to the inch, is used. For mapping thickly settled or industrially important areas a still larger scale, $\frac{1}{62,500}$, or approximately 1 mile to the inch, is used for quadrangles of 15′ each. A fourth scale, $\frac{1}{31,680}$, or exactly one-half mile to the inch, is employed for maps that are used in connection with irrigation or drainage, and a few maps of mining districts are prepared on still larger scales.

In addition to the symbol showing the scale of the map, topographic maps also show the year the map was made, the approximate mean declination for the year the field work was done, and the names of the men who did the work.

The features shown on these maps are classed in three groups:

(1) Water, including seas, lakes, rivers, canals, swamps, etc.

(2) Relief, including mountains, hills, valleys, and other elevations or depressions.



FIG

[*To face page 10.*]

(3) Culture, including towns, cities, roads, railroads, or any other works of man.

The conventional signs used for these features are shown in Fig. 1.

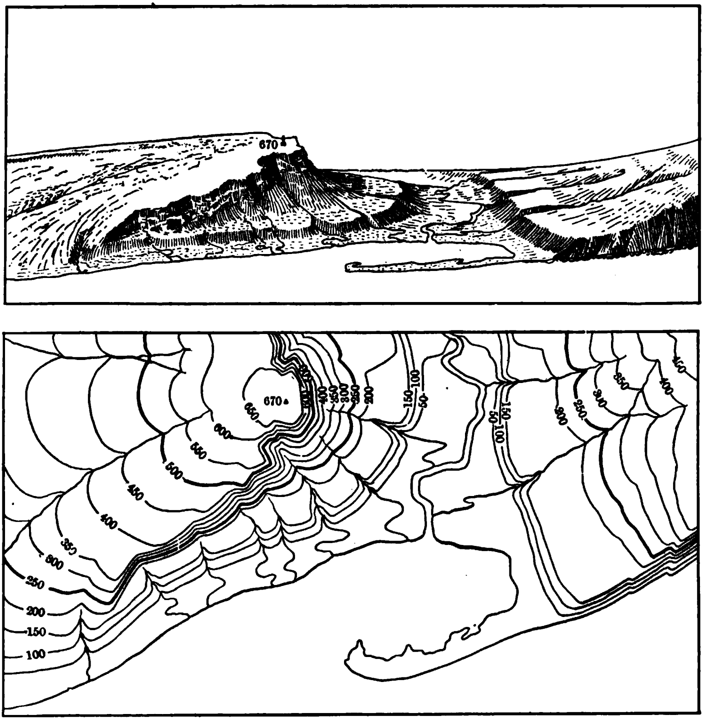


Fig. 2.—Ideal view and corresponding contour map. (U. S. G. S.)

All water features are printed in *blue*, and range from lines of dots and dashes for intermittent streams—those whose beds are dry at least three months in the year—to blue water-lining for large streams, lakes, and the seas.

Relief is represented by contour lines in *brown*, and a contour line on the ground passes through points that have the same altitude. The contour lines on the map show the shapes of the hills, mountains, and valleys, and their elevations. Thus a 20-foot contour represents what would be the shore line were the sea to rise, or the land to sink 20 feet, when sea level is used as datum, or zero of elevation. If the successive contour lines are far apart they represent a gentle slope; if they are close together they represent a steep slope; and when they run together they indicate a cliff.

The manner in which contour lines express altitude, form, and grade is shown in Fig. 2.

THE CONTOUR INTERVAL.—The vertical distance in feet between one contour and the next is stated at the bottom of each map, together with the datum used. This interval differs according to the area mapped; in a flat country it may be as small as 1 foot, and in a mountainous region it may be 250 feet. Certain of the contour lines, usually every fourth or fifth one, are made heavier than the others and are accompanied by figures stating the elevation above the datum used—usually sea level. In addition to the contour elevations the heights of many points, such as road corners, summits of hills or mountains, surfaces of lakes, and bench marks, are given on the map in figures, which express the elevation to the nearest foot only. If more exact elevations are desired they may be secured from bulletins for the several States issued by the United States Geological Survey and the bulletin for any State may be had on application to the Director of the Survey at Washington, D. C.

The works of man are printed in *black*, the color also used for lettering, and include such features as houses, roads, railroads, and all other features that are work of man rather than of nature. State, county, city, land grant, township, or reservation boundaries are shown by continuous or broken lines of different kinds and weights. Public and through roads are represented by fine double lines; private and poor roads by dashed double lines, and trails by dashed single lines.

In addition to the topographic maps prepared by the United States Geological Survey, some State surveys have issued topographic maps of special areas, the names of which can be obtained from the State Geologist.

Topographic maps, together with the geologic maps described later, form the best, and for many regions the only basis for careful geographic and geologic study.

From a proper study of such maps the geologist is enabled to draw valuable inferences concerning the nature of the rock and the accessibility of the area.

INTERPRETATION OF A TOPOGRAPHIC MAP.—A very rough and rugged topography generally indicates the presence of granite or other igneous rocks.[1] If the topography appears rounded rather than abrupt it may usually be taken to indicate the presence of soft sandstones and shales. Where escarpments or bluffs appear, combined with an otherwise uniformly developed topography, the general conclusion is that hard sandstones, or limestones, are interbedded with, or resting upon such more easily eroded formations as shales or soft sandstones. In some cases, however, as in regions of volcanic activity, these escarpments may be the result of a lava flow, which has formed a resistant capping for the softer formations beneath.

In addition to securing a general idea as to the nature of the rocks in a topographic quadrangle from the topographic map, the geologist can use the map to make a very close approximation relative to such costs of developing an area as are contingent upon railroads, villages, streams, and the accessibility of the site chosen for a test. Thus it is possible to determine the distance from the location of the test to the nearest water supply, and a route for the road over which the materials and supplies must be hauled to the location.

---

[1] This statement is a general one, as are the ones that follow, and will not hold true in every instance. There are no rules for the interpretation of rock formations from a topographic map which will hold true in every case, and those given here are therefore only those which will hold true in the majority of cases.

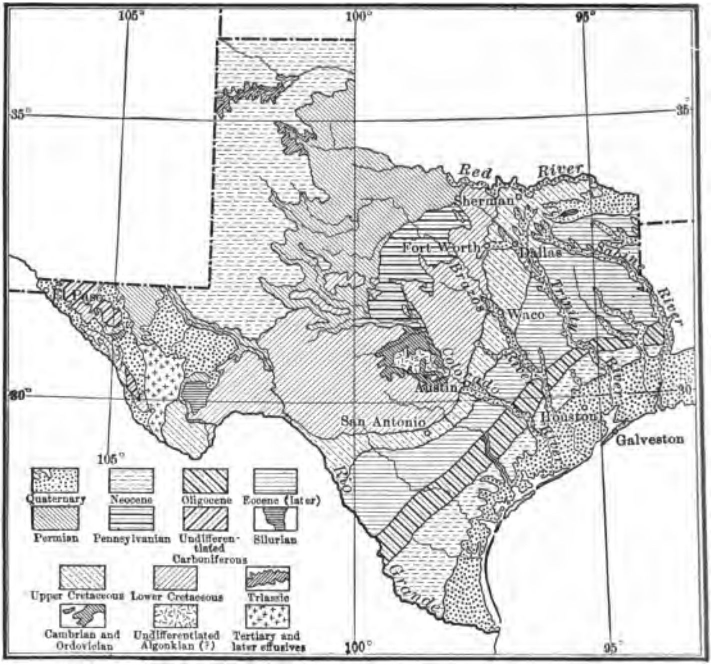


FIG. 3.—Geologic map of Texas. (U. S. G. S.)

Geologic Maps.—These are a representation of outcrops of formations, and show the location and relation to each other of the different geologic formations in an area. Like the topographic maps, they are made by the United States Geologic Survey and may be purchased from the Director. In some few cases geologic maps are prepared by the Geological Survey of the various States, as New York, Oklahoma, Texas, Kansas, etc., and may then be purchased from the Director of the State survey.

Geologic maps are generally prepared by using the topographic map as a base on which to represent the geology and geological conditions of the quadrangle. Starting with the topographic, or other base map used if the former is not available, the area covered by rocks of a certain age, or formation, is drawn to scale on the map either in the field or from notes taken in the field. When one formation has thus been represented on the map the other formations or ages of rocks are drawn to scale on the map in a similar manner, giving, when the map is completed, a representation to scale of the area covered by the various formations in the field. The relative ages of the rocks are indicated in the legend at the side, or base, of the map by means of letters, color patterns, or symbols, or a combination of these means, the symbols used corresponding to the different formations and being arranged in chronological order, the oldest at the bottom and the youngest at the top. By use of this legend it is a very simple matter to determine the age of the rocks which outcrop in any part of the area shown on the map. Thus in Fig. 3 the surface rocks at Houston are of Quaternary age.[1]

INTERPRETATION OF GEOLOGIC MAPS.—In the interpretation of a geologic map it is very essential to read correctly where one formation stops and another begins. This change is represented by a line separating the two symbols. Thus if on one side of a line is the symbol for Permian formations and on the other side is the symbol for Pennsylvanian rocks, then that line is the contact, at the surface, of the Permian and Pennsylvanian formations.

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[1] See Geologic Chronology Chart, page 116.

When an area of older rocks is found surrounded by younger formations, as is the case northwest of Austin (Fig. 3), it may mean either that an uplift has taken place at that point, or else that the older rocks were eroded down around this particular area now remaining, and the more recent formations were deposited up against the flanks of the older ones. If an uplift has taken place the presence of the older rocks within the younger ones may be accounted for in that the younger rocks, over the surface of the uplift, have eroded faster than on the flanks or beyond the edges of this uplift, and by this erosion have been worn down so as to expose the older formations along the axis of the uplift, while away from the axis the more recent rocks still conceal the earlier ones. A very good example of the representation of such a domed up structure (an anticline) which is also productive of oil is shown in the Lander, Wyoming, anticline (Fig. 4).

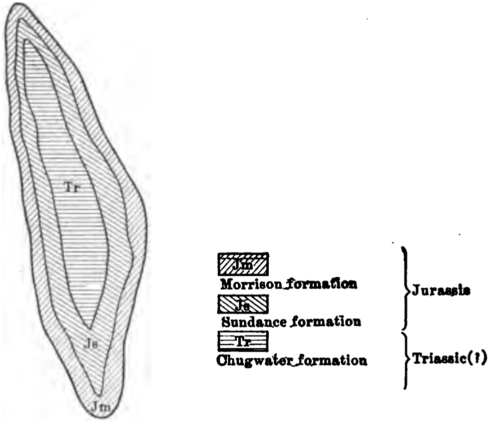

FIG. 4.—Showing manner in which an anticline may be represented on a geologic map; Lander, Wyoming, Oil Field.

If, however, the younger formations are found surrounded by older rocks it either means the presence of a syncline, or as in semi-arid regions, that they are capping buttes or mesas. When they represent a resistant capping for outliers they will show up as isolated knobs on the topographic sheet, and the same formations (the younger ones) will show up again some little distance away.

The occurrence of faults, either major (where one formation is faulted up against one of different geologic age, or minor—where there is only a small displacement of the beds in one formation) is represented on geologic maps by some symbol given in the legend, usually a very heavy line, either dashed or full. If the line is broken it means that the fault cannot be traced exactly over that particular area, while a solid line indicates that it shows up distinctly at the surface. The symbols for faults can be readily distinguished from boundary lines in that the latter are not quite such heavy lines as those representing faults.

Geologic maps are therefore used to determine the location of rocks of a particular age in an area, and to show the evidences of such major structural movements as great uplifts, depressions, or faults. On some of the maps the mineral resources of an area are also indicated.

Structure Maps.—This term is commonly employed in oil and gas geology to represent the structure of any particular bed or rock formation. By the use of contours—full when they are accurately mapped, and dashed when they are projected over an unmapped area or where no data are available—irregularities on the surface of the bed or formation are shown in the same way that hills, valleys, and other natural features are shown on topographic maps. In other words, a structure map is a topographic map of the surface of any bed, either at or beneath the surface of the earth. Maps of this kind covering different areas have been prepared by the United States Geological Survey, the several State

Surveys, and by private parties. These maps, however, represent only the structure of the bed and do not show the topography of the ground over that area. When it is desired to show both the surface and subsurface structure on the same map it is done by using different colors for the two sets of contours, but this is so seldom used that it will not be taken up and described.

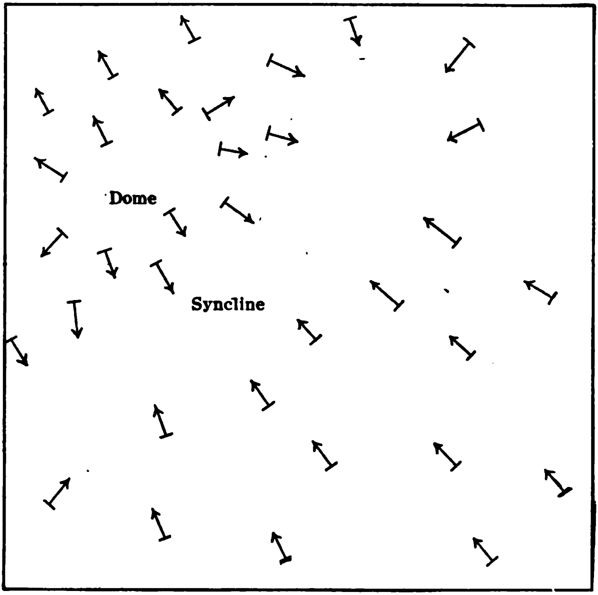

FIG. 5.—Dip strike symbol map with interpretation.

In some cases preliminary reconnaissance maps of the structure are prepared, on which changes in the dip of the strata are represented by dip and strike symbols as described under Reconnaissance Mapping (page 38). Such a map with its interpretation is shown in Fig. 5.

For the most part, however, structure maps are detail maps on which contours are used showing the shape and extent of the structure, either at or beneath the surface of the earth. Such structure maps showing the areas considered most favorable for the accumulation of oil and gas are shown in Figs. 6 to 9.

In the interpretation of a detailed structure map the arrangement of the contour lines is used to determine the structural conditions present, *i.e.*, whether or not an anticline, syncline, terrace, nose, or any type of structure be present, either favorable or unfavorable for the accumulation of oil or gas. Thus in Fig. 6 the increasing numerical value of the contour lines toward point *A* denotes the presence of a dome at that point, while the diminishing value of the contours toward point *B* shows a synclinal basin to be present at that point. In the case of a dome the contours are more nearly circular than in an anticline (Fig. 7) where they dip away from the high point at *A*, but they start closer to the center

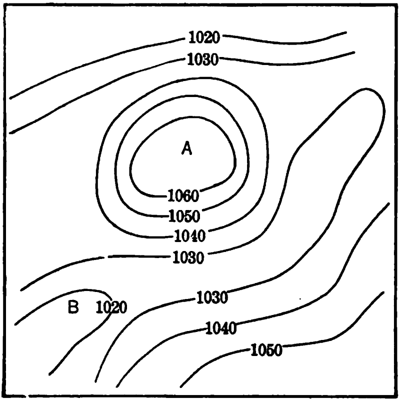

Fig. 6.—Structure contour map of a dome.

toward the sides than at the ends, giving the structure a more elliptical shape. Fig. 8 represents a nose, or an elongation of one side of an anticline, usually the result of a tendency to the formation of one structure at right angles to another.

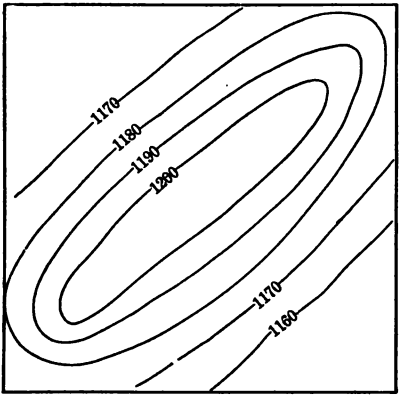

FIG. 7.—Structure contour map of an anticline.

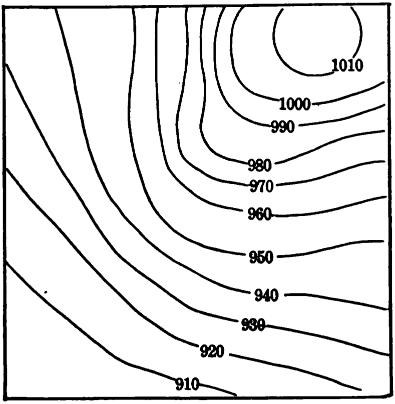

FIG. 8.—Structure contour map of a nose.

The high part of structure, in this case (Fig. 8), is a dome in the northeast corner of the map and a small nose extending out from this dome to the southwest, gradually merging into a uniform slope until it disappears at the 930-foot contour. In Fig. 9 is shown a contour map of a terrace which is a flattening out of a uniform dip. The formations are dipping to the south, but the uniformity of this dip is broken between the 770- and 760-foot contours, thus causing the development of a terrace before again dipping to the south.

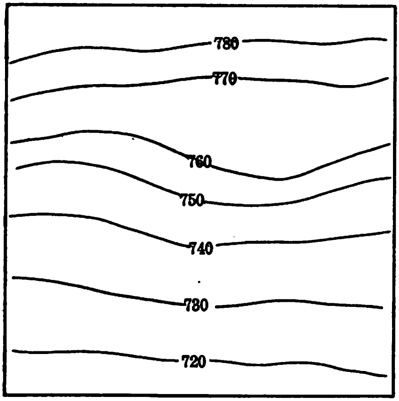

Fig. 9.—Structure contour map of a terrace.

There are various other types of structure which are modifications, or combinations, of the above types, and may be best studied in the field, as they vary so in detail as to make it almost impossible to attempt to illustrate and describe them.

Maps representing structural conditions are of the greatest value to the oil geologist. By their use the geologist in the field represents the existing conditions. Other geologists are then able to take these maps and determine the size, shape, and trend of the folds, as well as the most favorable location for a test well if the region has not already been proved. When the area has already proved productive the use of a structure map, together with a convergence sheet, described on pages 52 to 54, will give a very correct idea of the exact shape and location of the producing sand.

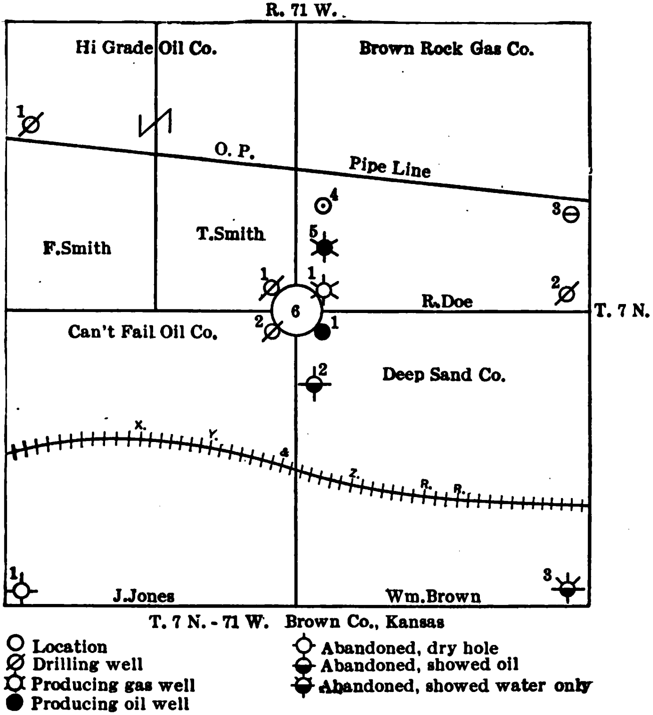

FIG. 10.—Ownership map of one section.

Ownership Maps.—Besides the use of topographic, geologic, and structure maps, a considerable use is made of ownership maps in any prospective or producing area. These maps show the name of the owner of the land, the companies, or individuals, that have leased the oil, gas, or mineral rights from the owners, and generally show the locations of roads, railroads, pipelines, and wells already drilled within the area (Fig. 10). The various features shown on the ownership maps are represented by symbols. Thus in Fig. 10, in the northwest $\frac{1}{4}$ of the section, T. Smith is the owner of the east half of the $\frac{1}{4}$ section, and F. Smith is the owner of the west half; Hi Grade Oil Co. has leased land from both owners as shown by their name being printed across the top of the entire $\frac{1}{4}$ and the small |/| which joins the two leases; the Hi Grade Oil Co. are drilling their first well on the T. Smith lease in the southeast corner of his farm, and their first well on the F. Smith farm is being drilled on the north side of the O. P. pipe line. The number of each well is shown by the small figure above the symbol for the well, as on the J. Jones farm in the southwest $\frac{1}{4}$ of the section, where the Can't Fail Oil Co. drilled and abandoned their first well in the very southwest corner, and are now drilling their second well in the northeast corner of the farm.

Ownership maps may be either of a small territory or, as is more common, cover a township, and in some cases extend over an entire producing district or county. They may usually be purchased from abstractors or real estate firms, and in some instances from the county engineer, or surveyor.

Since the use and making of ownership maps comes under the work of the Land and Lease, or Scouting, rather than that of the Geological department, they will therefore not be taken up or described further.

County Maps.—These are maps showing the streams, roads, railroads, townships, and villages, together with the location of producing oil or gas districts. Such maps are more detailed and of larger scale than State maps, and are also usually more up to date than the Government maps in regard to the location of roads and other cultural features; but they do not show the relief of a region. County maps are made by the county surveyor, or engineer, and may be obtained from him. They are of especial value to the geologist in the field, since they give the location of schoolhouses, churches, roads, and railroads very accurately. A person in the field is thus enabled to locate himself very closely, as well as to determine in advance what roads will be open for travel.

Township Maps.—This type of map is most commonly used by oil companies as a base map for field mapping, especially in those regions where the land has been divided up into sections by the government.

In the surveying and opening up of new lands by the United States Government the areas have been divided up into geographical townships of 36 square miles each. These townships are bounded on the north and south by township lines laid off parallel to some line of latitude, and on the east and west by range lines along meridians to the east and west of some principal meridian. When the area has thus been divided up into rectangles of 36 square miles each they are then numbered east and west from the principal meridian used and north and south from the line of latitude used (Fig. 11). Once the area is divided into townships it is further subdivided into sections of 640 acres each. These sections are each approximately a mile square and are numbered consecutively from 1 in the northeast corner to 36 in the southeast corner (Fig. 11).

For the purpose of this surveying and division of the area into townships and sections the surveys are all made from the south to the north and from the east to the west. By this method any correction due to the convergence of the meridians is always thrown along the west side and chiefly in the northwest corner section (6) of the township. It is necessary to make this correction in order that the townships be of as uniform a size as possible and yet have the north-south lines running true north-south. This correction is usually made every 24 miles, or as in some States every 30 miles, to the north and south of the principal lines of latitude used.

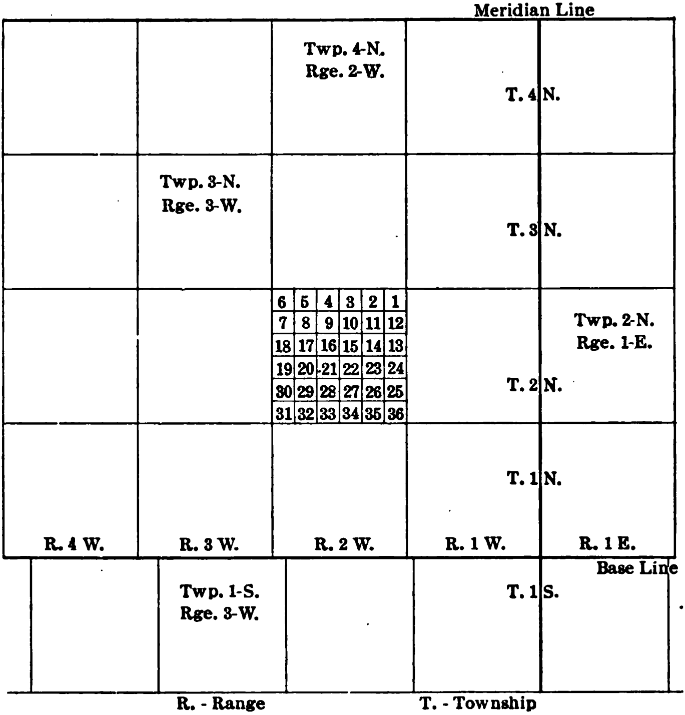

FIG. 11.—Showing method used in numbering sections, townships, and ranges.

When the township has been laid out and divided up into sections and correction made for the meridian convergence, the sections are then divided into quarters of 160 acres each, and each quarter subdivided into quarters of 40 acres each. Thus by the township maps it is very easy to designate a particular tract of land, as the farm of John Jones in the southeast ¼ of the northeast ¼ of section 21, township 2 south, range 4 west, Indian Meridian, Stephens County, Oklahoma. When a tract of land is thus described it can be located with great accuracy on any map of the State of Oklahoma which shows the sections, whereas it would be foolish to attempt to locate any particular tract on the map of any State which has not been divided up into sections, townships, and ranges.

This method of describing locations of land is the one used by all companies to describe the location of their leases, and by a further subdivision of the quarters to describe the location of wells. It is therefore essential that the geologist have a clear conception of the method of land survey and division as adopted by the United States Government, and if it is desired to go further into detail in the subject the following book is recommended:

"The Principles and Practices of Surveying," by Charles B. Breed and George L. Hosmer. John Wiley & Sons, Inc., of New York.

The following books are also recommended as being adapted for a study of field mapping, sketching, and map interpretation:

1. "Topographic Instructions of the United States Geologic Survey." May be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C.
2. "Topographic Maps and Sketch Mapping," by J. K. Finch. Wiley & Sons, New York.

3. "Map Reading and Topographic Sketching," by E. R. Stuart. McGraw-Hill Book Co., New York.
4. "Map Reading for Aviators," by C. B. Benson. Cornell Co-operative Society, Ithaca, N. Y.
5. "Military Sketching and Map Reading," by Capt. J. B. Barnes, U. S. A. D. Van Nostrand Co., New York.
6. "Topographic Drawing and Sketching," by Lieut. Henry A. Reed, U. S. A. Wiley & Sons, New York.

CHAPTER III

FIELD MAPPING AND METHODS

In the course of geological field work the geologist is called upon to make various maps, the most common of which are surface-structure maps, both detail and reconnaissance, and subsurface maps—structure maps of some bed or formation beneath the surface, such as a producing oil sand. Geologic, topographic, and farm maps are also sometimes made by the geologist, but so seldom that they will not be taken up.

Surface Detail Maps.—In the preparation of surface-structure maps in detail, the surface of some persistent bed in the field is chosen as the key horizon, its elevation determined at a number of points, which are then located to scale on the map, and lines then drawn through points of equal elevation on that surface, as plotted on the map of the area. Thus when the map is completed there is a graphic representation of the surface chosen, showing the form of the folds, their steepness of slope, and the altitude of many points on the bed. These features are shown in varying detail, according to the contour interval chosen, the number of elevations taken, and the accuracy with which such elevations are determined, together with the correctness of the location of the outcrop.

METHOD OF MAP MAKING.—The general method in use for the making of structure maps of surface formations in detail consists in first determining which one of the outcropping beds in the area can be most readily followed, and at the same time is extensive enough to servc as a key horizon. This key horizon is commonly called the "Datum."

When the bed has been selected the geologist determines the course of the outcrop and elevations along it by means of the plane table outfit (Fig. 12). The use of such an outfit requires the assistance of a second man, the instrument man. The geologist traces the course of the outcrop and at frequent intervals, usually every 300 to 500 feet, raises the rod for the instrument man to take an observation, thus determining the location and elevation of the outcrop at that point. This location is then plotted on the map, to scale, and the elevation recorded either on the map or in the notes. The method of taking observations on the rod, and the computing of distances and elevations is described on pages 58 to 63. Thus the geologist traces the line of the outcrop throughout the area, and while doing this should be also studying the field conditions as described in Chapter I. The instrument man takes observations, or readings, on the rod, computes distances and elevations and plots the results on the map.

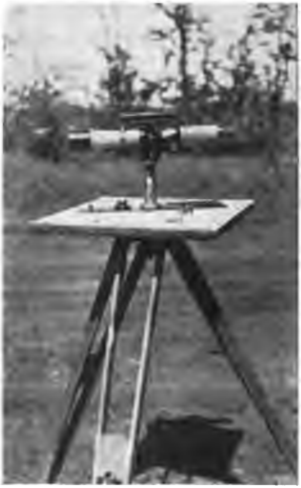

Fig. 12.—Plane table outfit.

While this method of work requires the employment of two men, and is often slower, yet it is the most accurate method used, and the maps thus secured will be found to be of greater value than any other type, especially in "wildcat"[1] areas.

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[1] A term commonly used to designate an area which has not been proven either productive or unproductive.

When it is desired to map the area in shorter time and with less detail, the course of the outcrop may be determined by the use of a "Brunton Patent Pocket Transit," and elevations secured with an aneroid barometer or stadia handlevel. This method of rapid mapping is taken up and described under Reconnaissance Mapping (pages 38 to 41).

In either case the elevations should be taken along the outcrop at intervals of from 300 to 1000 feet, depending upon the scale of the map, the accuracy desired, the steepness of the slope, and the regularity of the formation.

If it is desired to keep a check on the results it may easily be done by "taking shots"[1] at occasional intervals on some upper or lower bed, all strata being considered more or less parallel in the absence of faults or unconformities.

It will often be found that it is better to drop, for the time being, the outcrop that is being carried, and use some other stratum. Such a case might occur where another bed has a more marked outcrop, or a surface which is more readily accessible, or where the bed being followed pinches out or dips beneath other formations. In any event, when dropping one bed and "picking up"[2] another, or when taking check observation on some parallel horizon, or bed, the correct interval between the two must be determined, and either added to or subtracted from the elevation secured, according to whether the new bed is below or above the key horizon. This interval between the beds must be measured normal to them. If the interval cannot be secured between the outcrops on the surface, it may be readily calculated by determining the surface distance between the outcrops, the angle of dip, and then computing, using the formula $x=d$ sine α. In this equation, x is the interval desired, d the distance between the outcrops, and α the angle of dip. Thus if two beds are dipping beneath the surface at an angle of 3° and their outcrops at the surface are 700 feet apart, then the interval between the beds is 36.6 feet.

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[1] The term used to refer to the taking an observation on the stadia rod, and the determination of distance and elevation.

[2] The tracing the course of an outcrop other than the one previously followed.

$$\alpha=3^\circ \quad \text{sine } 3^\circ=.0523$$

$$d=700 \text{ feet}$$

$$x=700\ (.0523)=36.6 \text{ feet,}$$

the correct interval between the beds.

Tracing the Outcrop.—When following the course of the outcrop valuable inferences concerning the structure may be often drawn from conditions existing at the surface. For example, if a hard resistant stratum is covered by a thin veneer of surface soil, the slope of the surface will represent quite accurately the amount of dip and its general direction.

In addition to observing the surface conditions the geologist has to be very careful to secure his elevations on one formation, or on formations from which he can compute the elevation of the key horizon for that point. In this tracing of one or more beds it not infrequently happens that the rock will be obscured for some distance by surface soil. When this occurs it is necessary either to correlate across the area where no outcrops appear or to trace the bed from surface evidence, and for the latter the following hints may prove useful, having been found very satisfactory in many regions:

Methods of Tracing Covered Beds.—Formations which are obscured may sometimes be traced by following the highest occurrence of float fragments from those beds as they appear in the soil, for it is evident that pieces of rock from any bed cannot work up a slope to any degree by natural means,[1] and hence when such rock float is found along a slope it is very good evidence that the bed being followed is underneath the soil at the place where the float occurs.

The appearance of numerous springs along a slope will often serve as a key to the location of a particular sand horizon which is known to be a source of water in that vicinity. A more resistant stratum will often form benches along the hillsides, thus permitting the ledge to be followed even though the rock itself does not outcrop.

Accurate observation of the flora present along a horizon may sometimes serve as a key when the strata themselves are not exposed. Thus if it has been noted that a particular kind of plant grows more rankly and to greater heights along a particular formation, the bed may be traced for some distance by following the line of most luxuriant growth of that plant.

SLUMPING AND CROSS-BEDDING.—When following any formation the geologist must be very careful to determine whether the beds are in place, as a slumping of the rocks may often be taken for a reversal of dip and a non-existing structure be mapped as a result of too hurried observations. This is especially true in case the stratum being followed is gypsum, and to a lesser extent when the formation is limestone.

Further care is necessary to observe if the dips recorded are a result of folding, or caused by cross-bedding. This can usually be determined by taking as many dip readings as possible. If they vary considerably over a small area it is safe to say that they are a result of cross-bedding or a very close folding of the sediments rather than a result of movements of sufficient extent to develop structures favorable for the accumulation of oil or gas.

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[1] In glaciated areas such fragments may sometimes be found above the bed, having been carried there from some distance by the ice as it moved over the region, but this can be determined by the fact that such pieces of rock are generally scattered for considerable distances above the formation itself.

CORRELATION OF THE BEDS.—When in determining the course of the outcrops and securing elevations on those beds it becomes necessary to cross an area where no outcrops appear and surface evidence of the bed is lacking, a very close observation and correct correlation is required on the part of the geologist in order to secure a correct map, as a mistake in correlation will nearly always give misleading results from those existing in the field.

In areas where fossils are present and where the beds have distinguishing characteristics, such correlation is easily and readily done. If the bed being followed contains a distinctive fossil, not found in the formations above and below, it is only necessary to find the stratum carrying that fossil to correlate across the area having no outcrop. Where the fossils have a wide range over several formations, however, they cannot be used alone as a method of correlation, and it is then necessary to make a careful study of the beds above and below the one being followed. For example, if a limestone is immediately above a red and brown shale, and that shale occurs in connection with no other bed than the limestone being followed, the correlation can be accomplished by finding the red and brown shale and locating the limestone immediately above it.

Where fossils are not present and the beds have no distinguishing characteristics, the use of a carefully prepared vertical section of the formations will often be found valuable for correlative purposes. This vertical section will be of use, however, only in such regions as have parallel beds of considerable extent, for it can be easily understood that such a section would be of no value in regions where the different strata pinch out, or thicken up, in relatively short distances, or change in character along the outcrop. Where, however, the beds hold up well, the vertical section can be prepared and used as below where section A represents the key section and bed 1 is being followed, section B represents the section found across an area of no outcrops and bed 1 is the same as in section A.

Section A.	Section B.
2 feet dolomitic limestone	7 feet brown clay shale
28 feet brown sandy shale	2 feet dolomitic limestone
3 feet coarse red sandstone (1)	27 feet brown sandy shale
15 feet gray clay shale	*3 feet coarse red sandstone* (1)
4 feet massive blue limestone	16 feet gray clay shale
8 feet gray sandy shale	4 feet massive blue limestone
6 feet blue clay shale	

There are some regions which cannot be correlated by either of the methods described above. Regions of this nature are exemplified by the Red Beds of the Permian which contain practically no fossils, and where the individual formations thicken and thin in comparatively short distances. In such localities as this correlation is extremely difficult and should be attempted only by a person thoroughly familiar with every phase of the rocks for that particular area, and even then the results can be carried for but short distances and are often questionable. This being true, there are no particular methods of correlation in the Red Beds, and the best results are generally obtained by a very close study of all the formations and their various methods of occurrence, and from the information thus obtained a fairly accurate general, rather than detailed, idea of structural conditions may be secured.

Contouring of the Map.—When the geologist has determined the course of the outcrop and it has been mapped and elevations computed by the instrument man, the next step in the preparation of a detailed structure map is the contouring. This can best be described by the aid of diagrams (Figs. 13, 14, and 15).

In Fig. 13 is a copy of a map showing the course of the outcrops and elevations along the exposure, these elevations having all been reduced to that of the key horizon. Since it is necessary in contouring a map to connect the points of equal elevation, and it is impracticable to connect up all points on the map which have an equal elevation, it is the accepted custom to select and use some contour interval. This interval represents the vertical difference in elevation between any two adjacent contour lines, and varies according to the scale of the map and the steepness of the dip. Having chosen the contour interval (10 feet in the diagrams), the next step is the drawing of the contour lines. Starting at

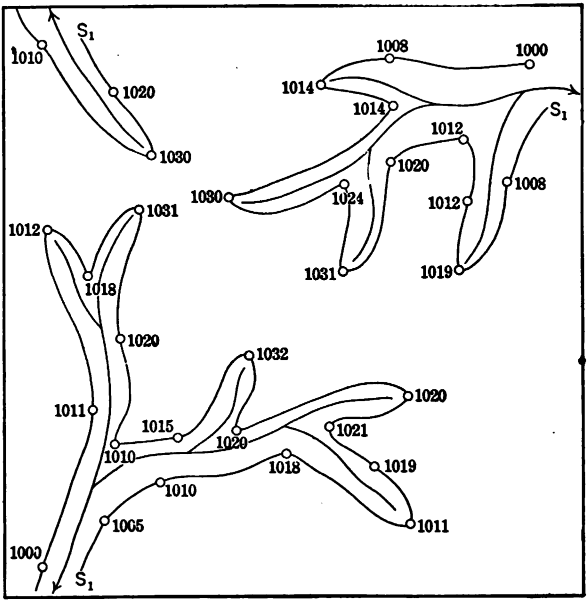

FIG. 13.—Detail map showing elevations.

some point whose elevation is divisible by 10 (the contour interval), a line is drawn through all points having the same elevation. In the contouring of a map, however, there will be found various points on the map through which a contour line should pass but where there will be no elevation divisible

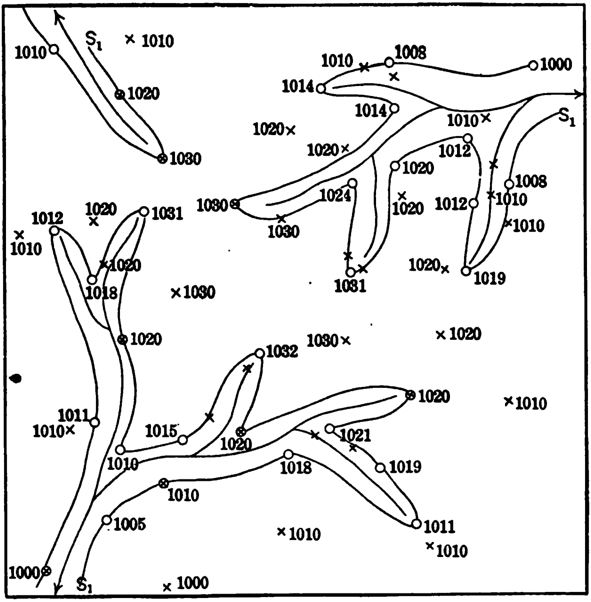

FIG. 14.—Detail map showing elevations and points through which contours should pass.

by 10, and it then becomes necessary to approximate the location of that point from two other adjacent points, one being greater than the value of the contour line and the other less. In Fig. 14 it will be noted that there is no 1010 foot elevation in the northeast part of the map, but a point is found with an elevation of 1008 and another with an elevation of 1014 feet. To obtain the location of the 1010 foot elevation point the distance between the two known points is divided into as many equal parts as are obtained by subtracting the lesser from the greater elevation, which in this case gives a remainder of 6. The interval between the two

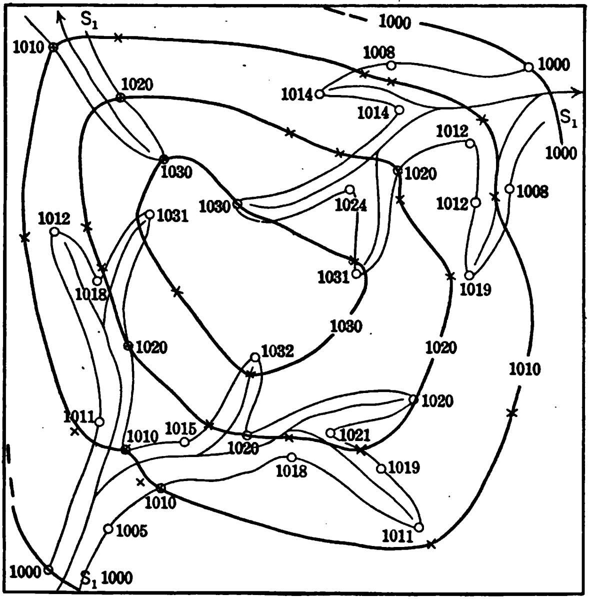

Fig. 15.—Detail map with contours drawn on a surface formation (S′), showing form of structure present.

points is therefore divided into 6 equal parts to which values are assigned from 1008 to 1014, and as the location of a point having an elevation of 1010 feet is desired, it is obtained by counting up two divisions from the elevation of 1008 and making a small *x* at that point. This *x* then marks the division through which the 1010 foot contour line will pass, and in like manner all such points are secured, through which a contour line is to pass but which do not appear as direct computed elevations on the map. The result of locating such points is shown in Fig. 14 where the controlling points for contour lines are marked by a small *x*.

When one contour has been drawn the others are then drawn in succession by connecting all points having an elevation equal to the contour interval and located either above or below the previous contour line drawn on the map.

In this manner, by locating the points through which the contours are to pass (Fig. 14) and then connecting those having equal elevations, the form of the surface of the key horizon is graphically represented (Fig. 15), just as the surface of the earth is depicted by a topographic map. This method of contouring a map described above applies either to surface structure maps, or to structure maps of some subsurface bed, on whose surface elevations are known.

Reconnaissance Mapping. Reconnaissance maps may be either maps which show only the general course of the stratum, with symbols to illustrate the dip and strike (Fig. 5), or they may be more in detail, representing more accurate locations of the outcrop with elevations taken by an aneroid barometer or stadia handlevel.

Where the map is to show only the dip and strike of the outcrop, as it is found throughout the area, the observations may be taken with a "Brunton Patent Pocket Transit." This is done by determining the strike of the bed—the line along which the stratum intersects the horizon—and then measuring the vertical angle of the dip at right angles to the line of strike. Thus if the strike of the bed is 45° to the north of west, then the angle of dip will be measured either 45° to the north of east, or to the south of west, depending upon which way the bed is dipping, as the strike will be the same for a true northeast or southwest dip. The method of measuring the vertical angle of dip is described on page 69.

The dip strike symbols when placed on the map will then show whether or not a favorable structure be present (Fig. 5); and while they show the presence or absence of folds they do not give any idea as to the size, except in a very general way.

Maps representing structure by dip and strike symbols

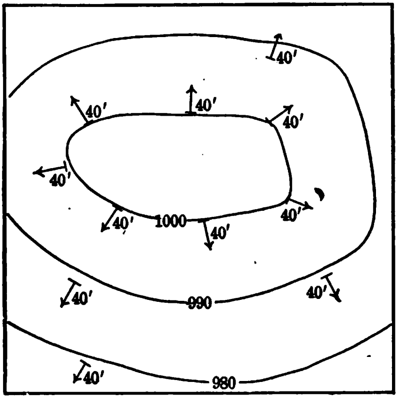

FIG. 16.—Showing method of contouring a dip strike symbol map. (The elevations of the contours are assumed.)

may be contoured (Fig. 16) but such contours are merely relative and not exact. If, however, it is desired to contour such a map, it is done by determining the dip in feet per mile in the various directions, plotting the points and connecting by contour lines. Thus if the dip is 40 feet to the mile to the north it means that starting at the point where that dip begins and going one mile north, and using a 10-foot contour interval, there will be 5 contour lines crossing that mile. This can easily be seen since if we assume the elevation of the contour line at the beginning of the north dip to be 1000 feet, then the elevation of the contour one mile north will be 960 feet and there will be a contour line every $\frac{1}{4}$ mile.

When it is considered advisable to secure a more detailed map than the one described above, and yet not use a plane table outfit, the following method is often used:

Determine directions by reading horizontal angles with the Brunton compass (described on page 68) and plot them on the map; having correctly mapped the location line from one point to the next we may secure the elevations by taking readings on the aneroid barometer (page 71), or by carrying an approximate traverse with the stadia handlevel (page 73).

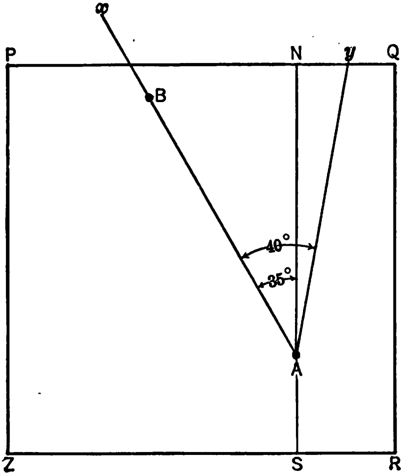

Fig. 17.—Method of locating points by plotting horizontal angles.

Having obtained the location line and elevation of an unknown point with reference to a known one, it is only necessary to determine the distance before it can be plotted on the map. The distance may be secured by pacing and computing from the number of paces taken times the length of the average pace, or it may be secured direct in tenths of a mile from an automobile speedometer, or by multiplying the circumference of a wagon wheel by the number of revolutions made in going from the first point to the second. In Fig. 17, starting at point *A*, which may be plotted at any place on the map, and sighting with the Brunton to the next point desired *B*; read the horizontal angle from either north or south. This angle when corrected for declination (see page 71) should then be plotted on the map from point *A*, giving the line *A–x*. A small protractor can be easily carried in the pocket and furnishes the best means for plotting the angles, and for this work cross-section paper should be used. Having plotted the direction from *A* to *B* on the map, the distance between the two points may be secured by any of the methods described above and scaled in along the line *A–x*, starting from *A*. The result will be an approximately correct location of point *B*, depending upon the accuracy of the determinations made. The elevation of *B*, relative to *A*, may be secured as mentioned above, and either recorded on the map or in the field notes.

CONSTRUCTION OF A PACE SCALE.—If the distance is obtained by pacing, a pace scale will be found very useful, and a very convenient method of making one is therefore given below for use when double paces are used, that is counting as one pace each time the right foot hits the ground.

Suppose that a pacing scale is desired for use on maps having a scale of 4 inches to the mile.

Lay off on a piece of good, thick paper a line 4 inches long (*A–B*, Fig. 18). Then divide the number of feet in a mile (5280) by the length of one pace in feet—previously determined by walking several times over a known distance. Thus if the pace is found to be 5.4 feet there will be 998 paces to the mile, and the 4-inch scale is then to be divided into 998 parts, if one pace is to be used as the unit of measure. It will generally be found more convenient to use 10 paces as the unit and the scale will then be divided into 99.8 parts.

In order to secure a correct division of the line *A–B* into 99.8 parts the line *A–C* is laid off at any moderate angle from *A–B*. Then taking any convenient scale, as 100ths of an inch, begin at *A* and lay off along *A–C* 998-100ths, or 9.98 inches, giving an accurate location for the point *C*. Connect points *B* and *C*. Starting at *A* along line *A–C* draw a line from every 100th point (every inch) to line *A–B* and parallel to line *B–C*, giving the lines *D–D′* to *L–L′*, inclusive. The intercepted distances along line *A–B* then represent distances equal to 100 paces—thus *D′–E′* represents 100 paces; by dividing the line *A–D′* into 10 equal parts, each one of these ten divisions will then represent distances of 10 paces each. The line *A–K′* is then equal to 800 paces of 5.4 feet each, using a scale of 4 inches to the mile, and will be found very convenient for scaling in distances on a map where paces are the unit of measure. In

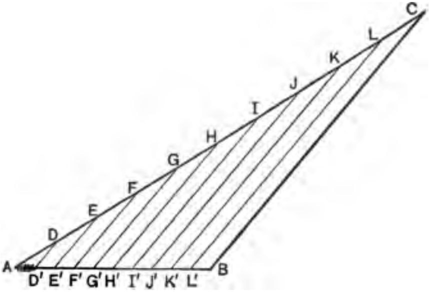

FIG. 18.—Construction of a scale; given scale of map and length of the unit of measure.

the same manner pacing scales can be constructed for any scale map and using any length of pace.

In pacing distances it is very essential that a natural step be taken. Then if the length of the pace is known the measurement of a distance is only a matter of counting steps. This counting can be done mentally and with practice will become subconscious, although care must be taken to avoid dropping 100 paces in such counting. It will therefore prove better to keep a tally of the hundreds, which may be done by keeping one hand closed and extending out one finger every time 100 steps are taken; and when all four fingers and the thumb are extended a mark can be made in the note book and the operation repeated. Thus if after pacing a distance it is found that 2 marks have been made in the book, 3 fingers are extended, and 27 paces was the last one counted the total number of paces is 1327.

On level ground pacing will be found to be accurate to within 4 per cent or less, but practice must be used to determine the average length of paces on slopes in order to reduce the error to the minimum.

When the distance is determined by the speedometer of an automobile it is read directly in miles and tenths of a mile and may be scaled in on the map by use of a scale divided in tenths of an inch.

If the distance is computed from the number of revolutions a wagon wheel makes in going from one point to the next, the formula $x=n(\pi d)$ is used, where x is the distance required, n the number of revolutions of the wheel, π represented by 3.1416, and d is the diameter of the wheel. For example, if the diameter of the wheel is 4 feet, and it makes 50 revolutions in going from one point to the next, then the distance between them is as follows:

$$x=50(3.1416\times 4)=628.3 \text{ feet, the distance covered.}$$

Thus it is possible to make a sketch map showing the approximate location of the outcrop and by use of dip strike symbols, or contours, when elevations are carried, secure a general or more detailed map of the structure, according to the method used.

In general it will be found that reconnaissance mapping will prove very satisfactory, if only a general idea of the region is desired, or when making a map preliminary to detailed structure mapping.

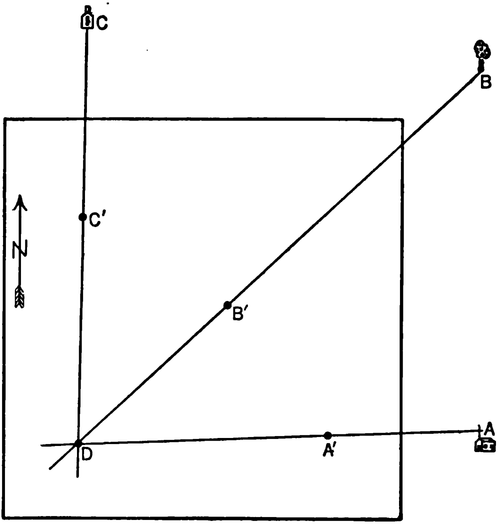

Fig. 19.—Location of an unknown point (*D*) by triangulation from three known points (*A*, *B*, and *C*.).

Some Useful Methods in Mapping.—When mapping an area, either in detail or reconnaissance, there are several "short-cut methods" which will assist in materially shortening the time required for the work, and yet not impair the accuracy. A few of these are therefore given and described.

TRIANGULATION.—The method of locating a point from two or more known ones is commonly called triangulation, and has been found very useful when desiring to secure a correct location without the carrying of a traverse. To do this, however, requires that the first two or more points used must be already plotted to scale on the map being made. In Fig. 19, when the points *A*, *B*, and *C* are already known and located on the map, the location of the unknown point *D*, may be obtained by orienting the map and then sighting through points *A′*, *B′*, and *C′*, as plotted on the map to points *A*, *B*, and *C* respectively in the field. Lines drawn along the ruler edge of the alidade[1] and passing through the known points when thus sighted, will intersect at the point *D* on the map which will be the correct location for the unknown point.

In like manner if a traverse is being carried and it is desired to secure the location of some object at a distance from the traverse it is done by sighting in turn from the various points at which the instrument is set up to the object in question. Lines drawn along the ruler edge of the alidade and parallel to these lines of sight will then intersect at the correct location of the point desired. This method of location is especially useful in "shooting in"[2] such distant objects as a watertower, a bridge across a stream, houses, oil derricks, etc. It can readily be seen that if a vertical angle (see page 62) to the same point on the object is read from each of the stations, when the location is secured by the intersection of the lines the distance that the point is away may then be secured by measuring (with scale) from the intersection of the lines on the map to any one of the stations used. Then knowing both the distance that the object is away and the vertical angle for that station the difference in elevation may be computed in the same way as when distance and angle are obtained from a reading on the stadia rod.

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[1] Telescopic alidade, the instrument used in detailed structure mapping, described and explained on pages 58 to 68.

[2] A term used to denote the taking of an observation on some object and then locating it on the map.

By this method the location, and a very close elevation, of any distant object may be secured without taking the time to carry a traverse to that point.

The distance away and the elevation of oil derricks may often be secured directly from the derricks themselves. A standard derrick has girts which are 8 feet from center to center, with the exception of the bottom and top ones; the bottom girt being 10 feet from the derrick floor, and the top one being 6 feet from the crown block (Fig. 20). Therefore if the number of girts and fractions thereof are read, in the same manner in which feet and tenths are read on the stadia rod, the distance may be computed within a very few feet. If, for example, 2½ girts are intercepted by either the top or bottom and the middle hairs of the telescopic alidade, then the distance is equal to 200 times 20 feet, or 4000 feet. (See page 58.) When the distance is secured by this method it is better to use a level reading (page 60) for the elevation. When the instrument is sighted at the derrick and leveled up, if it is seen that the middle hair falls midway between the sixth and seventh girts, then the derrick floor is 54 feet (10′+[5×8′]+4′) below the center

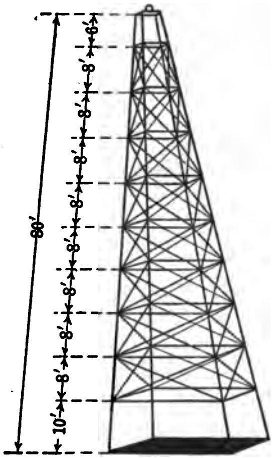

Fig. 20.—Standard derrick showing spacing of girts.

of the alidade. In using this method care should be taken to ascertain in advance whether the derricks in that particular area are standard ones or not, and this can usually be done by asking the operators or drilling contractors in the field. It is necessary to know this as some derricks are built with girts 7 feet apart instead of 8 feet, but when this has been found out the method of procedure is the same as though the girts were 8 feet apart.

Elevations on the Outcrop.—Oftentimes when detailing an area it will be found desirable to secure an elevation at the head of a small ravine which is densely grown up with brush, and where it would require hours of work to carry a traverse to the proper point. In such cases, where the distance is comparatively short—not more than 1000 feet—the elevation may be secured by the use of the aneroid barometer (described on page 71) and the distance estimated and the results recorded in the notes. The resultant elevation and location will not be quite as accurate as if done by transit, but with other nearby elevations to act as a check it will be found accurate enough for all practical purposes. Before doing this it is well to practice estimating distances, and in a short time it will be found that the estimates are quite accurate.

When it is desired to take an observation on the rod at some point which is hidden from the alidade by such objects as houses, oil tanks, etc., it is commonly done by pacing the distance from the point to a place where the instrument can be seen and then setting the rod up so that the elevation will be the same as at the point desired. Then, by estimating the direction from the point to where the rod was held and knowing the distance, the location desired may be correctly placed on the map. This method is very useful and accurate for short distances—300 feet or less—and it is seldom necessary to make use of it except for short distances.

Reconnaissance Triangulation.—In the preparation of a reconnaissance map of an area a rough system of triangulation may be carried on with the "Brunton Patent Pocket Transit." (See pages 68 to 71 for description and method of use.) This triangulation is accomplished by arbitrarily plotting some known point on the map (*A*, Fig. 21) and then reading the horizontal angles to points *B*, *C*, *D*, and *E* respectively and plotting these angles on the map from *A*, using a protractor and cross-section paper. Determine the differences in elevation of each of these points relative to *A* (see page 74) and record them either in the notes or along the lines of sight as plotted on the map;

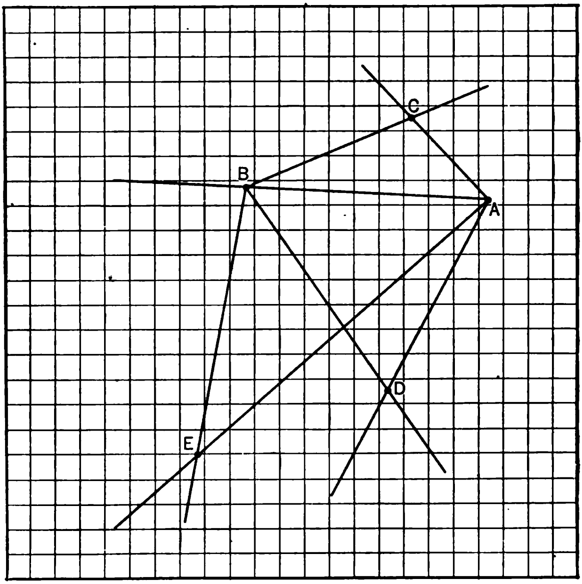

Fig. 21.—Method for reconnaissance triangulation, using a Brunton.

secure the distance from *A* to *B* by any of the methods described under Reconnaissance Mapping and plot point *B* on the map. From *B* the horizontal angles are read to *C*, *D*, and *E* and also plotted on the map. The intersections of the respective lines will then give the location of the points *C*, *D*, and *E* and the elevations have already been secured at *A* and may be checked from *B* if desired. By thus obtaining distances and elevations a fairly accurate map may be made very rapidly in open country where the outcrop shows up well. It also enables one to set elevations which may serve as future bench marks for aneroid work.

Checking Detail Traverse.—In carrying detail traverse and "closing in"[1] on some known bench mark it is not uncommon to find that the elevation does not check within several feet of the one previously recorded for that point, and in order that the traverse, and consequently the map, may be correct this requires a checking of the work to determine the location of the error and correct it. It is usually desirable to do this in the least possible time and thus keep down, as far as may be, the cost of the map. When looking for such error it is best to first check the notes in the book and make certain that the computations are all correct and then if the mistake is not found the traverse can be checked as shown in Fig. 22. In this case the traverse does not tie in for elevation, and in order to shorten the amount of work required for checking, the new traverse *X*–*Y* is carried. If this shows that the elevation at *Y* is correct with regard to the one at *X*, the error must then be between *X* and *Z*, or *Y* and *Z*; by carrying the traverse *W–Z*, if it is found that the elevation at *W* is not correct with respect to that at *Z*, it will show that the error is along the line *Z–X*, and this may then be recarried and the error found; should the elevation at *W* be correct with respect to the elevation at *Z*, the mistake is then between *Y* and *Z*. Whenever it is found necessary in the field to check a traverse for an error in elevation, it will be found that by carrying such cross lines the work required for checking will be shortened to a considerable extent.

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[1] A term used to denote the joining up of one traverse with another, or the ending of a traverse at the starting-point, or some other definitely located point. When the traverse closes in correctly the elevations of the two points should be the same, and the end-point of the traverse being carried should coincide on the map with the point to which the traverse is being closed with, and which must already be located on the map.

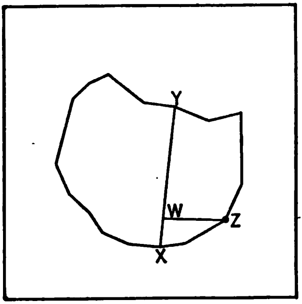

Fig. 22.—Showing short method for checking a traverse for error in elevation.

In some cases the location of the two points when the traverse is closed will not coincide, thus showing that there is an error in declination, and this must then be checked. When this is true it is best to check the entire traverse, should the error be more than a few hundred feet in the case of the ordinary map on a scale of 4 inches or less to the mile. If the map is to be very accurate, and on a larger scale, an error of 50 feet in declination will often require the recarrying of a traverse. That, however, will depend on the scale of the map used and the accuracy of the work desired, so no definite rule can be given.

Subsurface Maps and Convergence Sheet.[1] CONSTRUCTION OF MAPS.—The work of making a map of any particular stratum located at a considerable depth beneath the surface of the earth consists of three distinct steps: First, careful contour mapping of some prominent surface bed, called the key horizon; second, the ascertaining of the distance between this key horizon and the producing oil sand below, together with the amount and direction of variation in this distance; third, the application of a correction to the surface mapping equal to this convergence, so that lines drawn on the map connecting points of equal elevation (contour lines) will show the true shape of the oil sand, or particular stratum being mapped.

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[1] Abstracted from U. S. G. S. Bull. No. 318, Geology of oil and gas fields in Steubenville, Burgettstown, and Clayville quadrangles, Ohio, W. Va., and Pennsylvania. W. T. Griswold and M. J. Munn.

STRUCTURAL MAP OF THE KEY HORIZON.—When the geologist has completed the field work, as previously described, he has a map of the area on which are shown at hundreds of points the horizontal location and the elevation of the outcrops of the different beds mapped in the field. By a study of these outcrops the interval between the different strata is obtained, and one bed is selected as the key horizon, usually that outcropping over the greatest area. By adding to or subtracting from the elevation of other known beds the distance they have been found to be below or above the key horizon, the elevation of that stratum is obtained for all points taken, and when lines are drawn connecting the points of equal elevation, a contour map of the key horizon is produced.

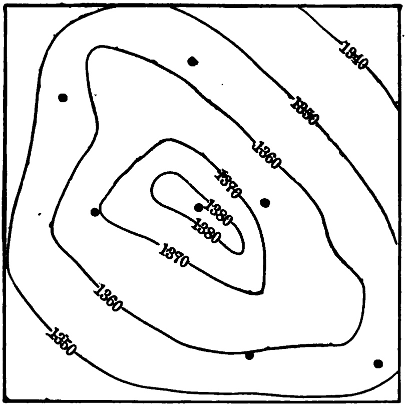
CONVERGENCE MAP.—From a study of the records of the wells in the different parts of the area a knowledge of the variation in distance between the key horizon and the subsurface stratum is obtained. Without these records it would be impossible to make any drawing that would show the form and position of the sand, unless it were exactly parallel with the key horizon.

To make use of the well records and construct an actual map of the oil-bearing sand the following method is most commonly used: Plot all the wells drilled within the area on the structure map of the key horizon. As the elevation of the mouth of each of these wells has already been determined—during the course of the field work, the position of the key horizon with reference to the mouth of the well is obtained directly from the map, and with this information the distance from the key stratum to the oil-bearing sand at that point is obtained from the record of the well. Thus if the key horizon is found to be 14 feet above the top of a certain well, and that well was drilled to a depth of 1111 feet before reaching the producing sand, then the distance from the key stratum is 14+1111 or 1125 feet.

By making this computation for each well of which a reliable record can be obtained, the distance from the key horizon to the oil bearing stratum is obtained in different parts of the area. In general this distance is not the same at different wells, but will decrease in one direction or the other.

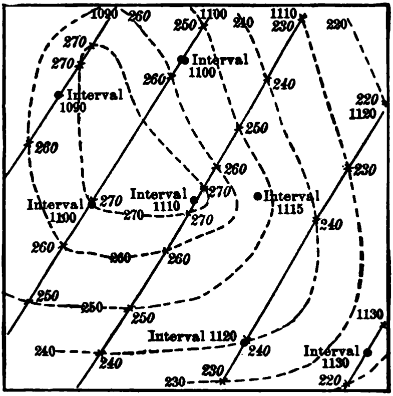
It is then necessary to correct for the convergence between the key horizon and the oil sand, and this is done by means of a mechanical drawing called a "convergence sheet." This drawing is made on tracing cloth by connecting the locations of the wells, from which reliable records have been obtained, by straight lines. These lines are then divided proportionately to the amount of convergence found between the two wells, so that each division of the line will represent an increased distance of 10 feet between the key horizon and the subsurface stratum, or oil bearing sand.

Having thus divided all the lines connecting the different wells, the points that show an equal distance from the key stratum to the oil sand are connected, giving a drawing that, when placed over the structure map of the key horizon, shows directly what distance should be subtracted from each elevation of the key stratum to make it equivalent to the elevation of the oil sand at that point.



A

Structure contour lines drawn on key horizon.



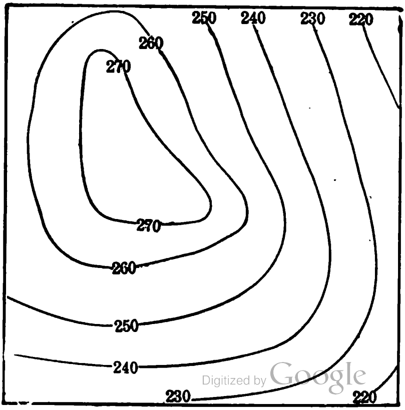
B

Convergence sheet.

Full lines—Contours of equal interval between key horizon and producing sand.

Dotted lines—Structure contours of producing sand.

Elevations *240*—Points on producing sand through which contours are to be drawn; secured by subtracting interval shown above from point where it intersects surface contour when imposed upon sur'ace contour map.



C

Structural lines drawn for the producing sand, as secured by use of surface structure map and convergence sheet.

Fig. 23.—*A*, *B*, and *C*.—Showing method of constructing isobaths for a producing sand by means of a convergence sheet.

In the preparation of this convergence sheet, records should be obtained from as many wells as possible, and the wells should not be spaced more than a mile apart, if it is possible to avoid doing so. It is better if they can be spaced within a quarter of a mile of each other.

The regularity and uniformity of this mechanical drawing will show whether or not it is possible to make a map of the oil sand that will be of practical value. If the distance between the 10-foot lines, called isochor lines (having an equal interval between the key horizon and the producing stratum), is regular and the decrease is uniform in one direction, a map of the lower sands can be made practically correct. When, however, the distance from the key horizon to the sand does not decrease uniformly, but first in one direction and then in another, there is little use in trying to interpret the structure of subsurface stratum from a map of the surface structure. It is beyond the fondest hope of the geologist that the wells have been located at the exact point of greatest distance between the two formations, and the resulting map will therefore probably be incorrect over limited areas.

The amount of convergence per mile is another important factor to be considered. When it amounts to 50 or 60 feet to the mile, there is little probability that the resulting map of the sand will be correct within a limit of from 20 to 30 feet. If, however, the convergence is less than 20 feet to the mile, then the resulting map should be of the same degree of accuracy as the surface structure map.

In making maps of subsurface strata in areas that have not been productive, most of the records used for the construction of the convergence sheet must be taken from wildcat wells. In many cases it is difficult to procure the records of such wells, and often the best that can be obtained is the depth, from some operator's memory, at which the sand was encountered; and the sand of which he speaks may or may not be the same one used in the construction of the convergence sheet. This is a source of serious error, for a mistake in this distance may make the final map incorrect for a considerable distance about the well, especially where there are no near-by wells to act as a check.

In preparing a subsurface map, a full knowledge should be had of the well records used for constructing the convergence sheet, and the reason given for discarding any reliable records whose distance would change the convergence sheet.

MAP OF THE OIL SAND.—When the convergence sheet is completed, the operation of making a contour map of the oil sand becomes very simple. The tracing is placed over the map on which are noted the elevations of the key horizon, and from each of these elevations the amount shown by the convergence sheet for that point is subtracted. The result is the elevation of a point on the oil sand, and by connecting the points of equal elevation with lines, a contour map of the oil-bearing sand is made. These maps are especially valuable in determining the apparent size and shape of an oil-bearing sand, and thus assist in computing the amount of oil that it may reasonably be expected to yield.

Preparing the Map and Report.—When the geologist has completed the field work in any area, it is then necessary to draw an accurate final map of it and give a report covering conditions in the region.

The map is prepared by making a copy, on tracing cloth or paper, of the map prepared in the field, and should show all outcrops, their location and elevation wherever determinations of it were made, the contours representing the topography of the key horizon, a geologic section of the rocks exposed in the area, the date and the name of the geologist, as well as a full and accurate description of the location. This description is given either by township and range, county and state; or by survey, county and state; or whatever method is employed in the area to describe the location of any given area.

If the work is done for some oil company by a geologist on the staff of that company, it is necessary only to make a tracing of the map as described above, while if the map is prepared by the geologist for a private individual or some company with which he is not connected other than as a consulting geologist, it is then required that a print be made from the tracing and inclosed with the report.

WRITING THE REPORT.—In preparing a report on any prospective oil or gas area the most important thing to be considered is that the paper be as brief as possible and still cover every condition in the area that in any way bears upon possible production. In order to do this it is best to have a clear and concise outline which covers the necessary points. Since, however, not all areas can be covered by the same outline or report, the form given below is general rather than specific, and should be modified, if necessary, to cover any particular region.

OUTLINE FOR REPORT ON AREA

I. Title.
II. Introduction. Reason for work, and acknowledgments for information.
III. Location. General and regional.
IV. Topography and drainage.
V. Accessibility and development at time of report.
VI. Geology.
  A. Stratigraphy.
    1. General features.
    2. Exposed rocks.

            - (*a*) Kind of rocks and character of outcrops.
        - 3. Rocks not exposed but present beneath the surface.
            - (*a*) Relation to other fields already producing.
    - B. Structure.
        - 1. Method of determining and representing.
        - 2. Regional structures.
        - 3. Local structures.
- VII. Prospective oil and gas areas.
    - A. Localities of favorable structures, with description.
    - B. Localities of possible favorable structures, with description.
    - C. Localities of unfavorable structures, with description.
    - D. Copies of well records in the area.
- VIII. Summary, giving general possibilities for development, and locations best suited for tests.

The above outline is intended primarily for use when describing an area as yet undeveloped, and when it is desired to write a report covering an area already productive it then becomes necessary to omit all general topics and deal strictly with specific cases. When the latter is true, it is necessary to take up a full interpretation of the well records and deal with such problems as water in the oil sand, methods of drilling, best method for handling wells, etc.

CHAPTER IV

FIELD MAPPING INSTRUMENTS, THEIR USE AND ADJUSTMENT

Telescopic Alidade (Fig. 24). This instrument is used in field geologic mapping to obtain distances and differences in elevation from stadia rod readings. In measuring distances with the telescopic alidade the horizontal hairs in the instrument are so spaced that the interception on the rod of the top and bottom hairs times 100 is equal to the horizontal distance that the rod is away from the center of the instrument; likewise the interception of either the top or bottom and the middle hair times 200 is the distance away of the rod. Thus if the interception of the top and bottom hairs is 2.5 feet (Fig. 25), the rod is at a distance of 250 feet from the alidade; if the interception between the top and middle,

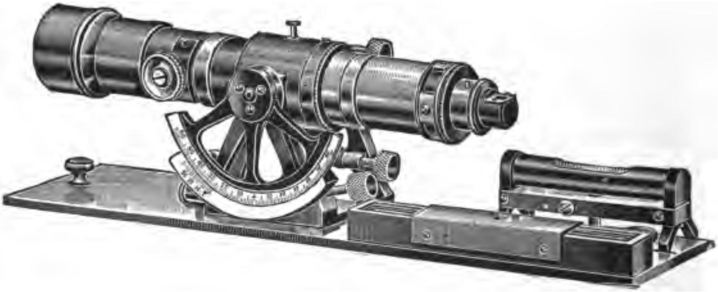


FIG. 24.—The Telescopic Alidade. (Courtesy of Bausch & Lomb Optical Co.)

or bottom and middle, hairs is 2.5 feet, then the rod is 500 feet away. Some instruments are further provided with a hair between the middle and one outside hair. This is known as the "quarter hair," and the interception between this and either adjacent hair times 400 gives the distance from the rod to the instrument. In Fig. 26 is shown a quarter interception of 2.5 feet, representing a distance of 1000 feet (400×2.5 feet).

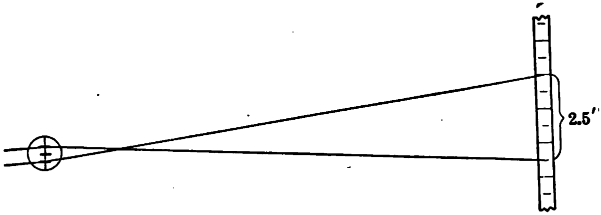


FIG. 25.—Showing interception of top and bottom hairs on rod. Distance, 2.5 ×100 = 250 feet.

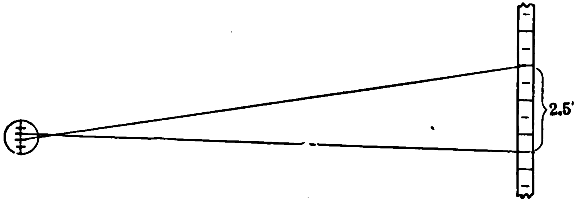


FIG. 26.—Showing interception of quarter and middle hairs on rod. Distance, 2.5×400 = 1000 feet.

In measuring distances it will frequently be found that the rod will be at a considerable angle above or below the instrument. When this is true, if the rod is held vertically, as it commonly is, it will not be perpendicular to the line of sight of the alidade, and the interval read on the rod will be too large and will have to be corrected. It is possible so to incline the rod that it will be perpendicular to the line of sight; but this requires very accurate judgment on the part of the rodman, and also tends to complicate the reading of the elevations. For the correction of such inclined stadia observations Stadia Reduction Tables are given on pages 97 to 105.

ELEVATION READINGS.—For reading differences in elevation with a telescopic alidade and stadia rod there are three chief methods:

(*a*) *Level Readings* are secured with the alidade by leveling up the telescope tube by means of the tangent screw and the striding level above the telescope. When the tube is perfectly horizontal the interception of the middle hair on the rod is then read. For such leveling of the telescope the tangent screw is turned either to the right or left, as the case may be, until the bubble in the striding level shows the instrument to be in a horizontal position, at which time the position of the middle hair on the rod represents the distance that the bottom of the rod is below the center of the instrument. If the middle hair is on 10.2 feet, then the center of the instrument is 10.2 feet above the base of the rod. (The center of the instrument is commonly called the "H. I.," or height of the instrument, when set up in the field.)

Often when the instrument is leveled the middle hair will be found to be either above or below the rod and elevations may then be secured by either the bottom or top hairs, if they fall on the rod. For example, if the middle hair does not fall on the rod but the bottom hair falls on the 14.2 foot mark, the difference in elevation will be 14.2 feet plus the interception on the rod of the middle and bottom hair; if the interception in the above case is 5.3 feet, then the bottom of the rod is 14.2+5.3, or 19.5 feet below the center of the instrument.

Should the middle hair fall below the rod, however, then the difference in elevation will be the interception of the top and middle hairs minus the elevation on which the top hair falls. If the interception of the top and middle hairs is 5.2 feet, and the top hair, when the instrument is level, falls on 1.2 feet, then the difference in elevation is 5.2−1.2, or 4 feet, the vertical distance from the center of the instrument to the foot of the rod.

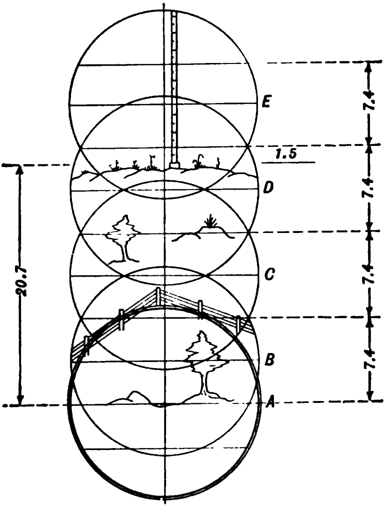


Fig. 27.—Method of stepping elevations. (Courtesy of Bausch & Lomb Optical Co.)

(*b*) *Stepping Elevations.*—This method of obtaining elevations is used when it is found impossible to secure a level reading for differences in elevation and it is not desired to read vertical angles and compute. When using the stepping method the instrument is first leveled as for the level reading of elevations, and the field of vision is then elevated or depressed, one interval at a time, until one of the hairs cuts the rod. This can best be understood from Fig. 27. In this case the rod is at a distance above the instrument and after the telescope has been leveled *A* it is then raised *B* so that the lower hair, or stadia wire, occupies the exact position of the middle wire in *A*. The telescope is then elevated by successive steps, each equal to the stadia interval, until the upper stadia wire cuts the rod *D*. The correct stadia interval[1] is then found *E* by setting one wire, the bottom one, on any convenient foot mark and reading the number of feet and tenths of a foot intercepted between the bottom and top stadia wires, the distance in the diagram being 7.4 feet. This interval times the number of steps (in this case 3) gives the total intercept (22.2 feet), or the distance between the upper wire in field *D* and the middle wire in field *A*. Since, however, in the diagram the upper wire in field *D* cuts the rod on the 1.5 foot mark, the difference in elevation between the base of the rod and the center of the instrument is $(3 \times 7.4 \text{ feet}) - 1.5$ feet, or 20.7 feet.

The stepping method for determining differences in elevation is well adapted to regions where such suitable objects as trees, rocks, oil derricks, etc., can be found which will serve as distinctive marks for the position occupied by the stadia wires in each field of elevation or depression.

(*c*) *Vertical Angles.*—When, however, it is impracticable to use the stepping system and impossible to use the level readings, the third method, that of reading vertical angles, is used. In this method after the telescope has been leveled the vernier is read and the angle recorded. The telescope is then elevated or depressed until the middle hair cuts the rod at some foot mark, as 10 feet, and the angle again read on the vernier and recorded. The difference between these angles is then found and the value for this difference determined from the table on page 96. This value times the distance between the rod and the instrument, with two places pointed off, ± the foot mark on which the middle hair was set, is equal to the difference in elevation. Thus if the level reading is 30° 10′, and the reading when the middle hair is set on the 10-foot mark is 26° 8′, this gives an angular difference of 4° 2′, which according to the Stadia Conversion Table has a value of 7.02. Were the distance 600 feet, then the difference in elevation is $(7.02 \times 6.00) \pm 10$ feet $= 32.12$ feet, or 52.12 feet according to whether the rod is above or below the alidade. When the rod is above the alidade the 10 feet is subtracted from, and if below added to, the amount obtained by multiplying the distance, with two places pointed off, by the value for the difference between the two angles.

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[1] The stadia interval is the interception of the top and bottom hairs.

In field mapping as done by aid of the telescopic alidade the map is made at the time, and in the field, by plotting all points on the map at the time they are located by the traverse. The plane table is first set up and then leveled and oriented, using the alidade. The leveling is done by adjusting the plane table until the small bubble on the base of the alidade shows the surface of the table to be level, and the table is then oriented by placing one edge of the alidade base along the line of declination, previously determined,[1] and turning the plane table until the needle comes to rest on the zero point. The table is then oriented true north and south. When this has been done the point from which the work is to start is plotted on the map, if it has not already been done. The ruler edge of the base of the alidade is then placed along this point and the telescope is so sighted on the rod—held over some point whose location it is desired to plot on the map—that the vertical hair apparently splits the center of the rod and the distance is then read as described above. This distance is scaled in along the line of sight (the ruler edge of the alidade on the map being parallel to the line of sight), giving the location, to scale, of the second point on the map, the accuracy of whose location depends upon the care used in sighting on the rod and the reading of the distance, as well as its scaling in. By moving the table to some other point in the field, orienting, and sighting through this second point on the map back to the rod held on that point in the field, measuring the distance and scaling in as before, the location of a third point is secured. In this manner an accurate traverse can be carried and scaled in on the map, at the time the readings are taken, and without the necessity of reading horizontal angles and computing, as is done when a surveyor's transit is used.

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[1] The line of declination is determined by drawing a line on the map from the north to the south, to be used as a true north-south line. A point is then located near the south end of this line. Set the plane table up, level it, and then place the ruler edge of the alidade along the true north-south and sight along some true north-south line in the field, such as a section line, or some meridian line. When the north-south line on the map is in direct line with the one in the field the plane table is firmly clamped to the tripod; the alidade is then revolved around the point already located on the north-south line until the compass needle points to zero, and when revolving the alidade care must be taken to see that the ruler edge of the instrument passes through the point above mentioned. When the needle comes to rest at zero a line is drawn along the edge of the instrument, passing through the point on the map, and this line is *the line of declination for the area where the observations were taken.*

LOCATION OF POINTS AWAY FROM THE TRAVERSE.—In detailed geologic mapping it has been found most convenient to carry what is known as a main traverse and then take observations from this main traverse to points on the outcrop, or other locations desired. This is done by making several determinations of distances and differences in elevation from one instrument station. In Fig. 28 the main traverse is carried through points *A*, *B*, *C*, *D*, *E*, and closed back to *A* again, but the observations on the outcrop are taken as illustrated by numbers 1 to 23. These side observations show the course of the outcrop, or other points desired, without the necessity of carrying a long and irregular traverse, passing through each point, and thus save considerable time in the mapping of an area.

TRIANGULATION WITH THE ALIDADE.—In addition to their usefulness in determining horizontal distances and differences in elevation, the alidade and stadia rod will be found the best instruments for intersection and resection work, commonly called triangulation, the methods of which have been taken up and described on pages 45 to 46.

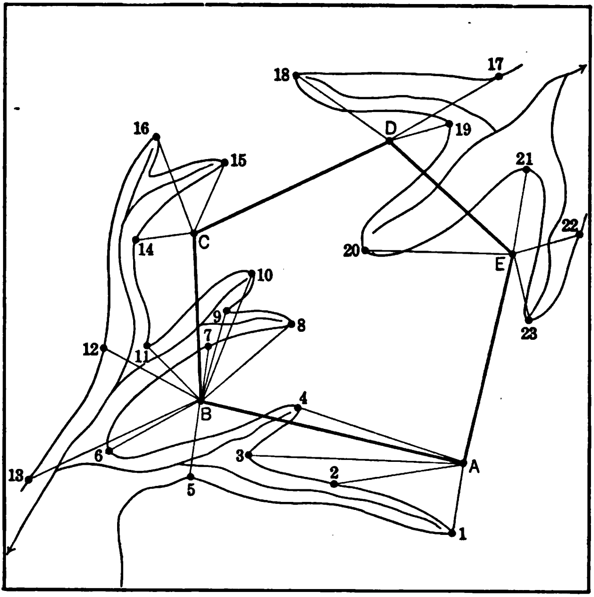

FIG. 28.—Method of taking observations at points not on the main traverse.

ADJUSTMENTS OF THE TELESCOPIC ALIDADE.—This instrument is so constructed as to need practically no adjustment in the field, with the exception of the striding level and stadia wires. Frequently during the work in the field it will be found that when the instrument is leveled up, by aid of the bubble in the striding level, and the level then reversed, the telescope no longer seems level. When this occurs it is necessary to adjust the bubble. This is best and easiest done by means of the little adjusting screw in the bubble support. Level the instrument, as though to take a level reading of elevation, and reverse the bubble—remove from the telescope, turn half way around and replace—noting the number of divisions on the glass by which the bubble in the second position differs from that when first leveled; then turn the adjusting screw until the error is reduced one-half, after which reverse the bubble again. A few trials will soon give the proper adjustment.

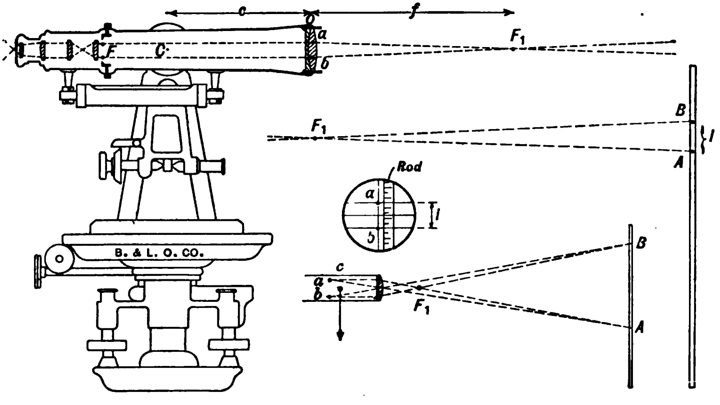

Fig. 29.—Showing constant of instrument, and intercepted interval on the rod. (Courtesy of Bausch & Lomb Optical Co.)

If in carrying a traverse the elevations do not check, when the traverse is closed, and no error can be found in recarrying the work, it is well to check the adjustment of the stadia hairs as follows:

Level the telescope and place a stadia rod at exactly 100 feet plus the constant $(c+f)$[1] from the center of the instrument, and note where the middle hair intersects the rod. Hold the rod in exactly the same position and mark precisely .5 of a foot above and below this intersection, and note whether the upper and lower cross hairs in the instrument intersect these marks when the middle hair is midway between them. If they do the hairs are in adjustment, but when they do not the stadia adjusting screws should be turned until all hairs bisect the target as described above. This test may be repeated at 400 feet plus the constant, but in this case the marks for the upper and lower hairs should be made 2 feet above and 2 feet below the intersection of the middle hair.

If it is believed that the middle wire is not in adjustment with the bubble, it should be tested by exactly leveling the telescope, placing the rod at a distance of about 200 feet and making a level reading of the difference in elevation. Measure the distance from the center of the instrument to the ground—the H. I.—and mark the place where the rod was held and also where the instrument was set up. Reverse the location of the rod and the alidade and secure a level reading as before. If the bubble and middle stadia wire are in correct adjustment the difference in ground elevation between the instrument station and the rod station should be exactly the same at both points.

When, however, the ground elevations do not check exactly for differences the instrument is out of adjustment, and the best method for adjusting it is to send it to the factory or to some person well qualified for making the necessary adjustments.

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[1] This constant is the distance from the center of the instrument to the anterior focal point (Fig. 29). It may be determined by focusing the instrument on some distant object and measuring the distances from the center of the objective back to the diaphragm, adding to this the distance from the objective back to the telescope axis.

"The Brunton Patent Pocket Transit."—This instrument is a combination compass, clinometer, and pocket transit, and experience has proved it a most valuable instrument for reconnaissance work. The following cuts, showing the most common methods of using the Brunton for field mapping, together with the descriptions for these methods, are given by permission of Wm. Ainsworth & Sons of Denver, Colo.

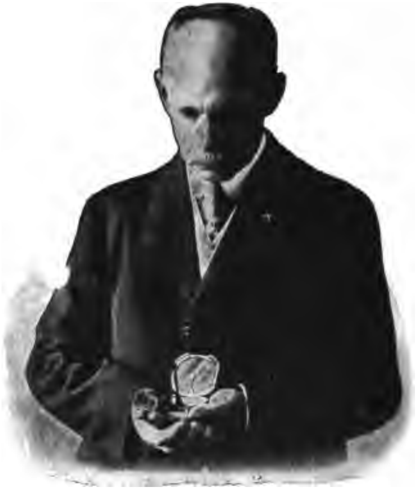

Fig. 30.—For courses or horizontal angles. (Courtesy of Wm. Ainsworth & Sons).

Horizontal Angles.—In taking courses or horizontal angles with the Brunton the instrument should be held as shown in Fig 30. The large bubble tube should be turned at right angles with the line of sight as in Fig. 31; when the bubbles show that the instrument is level it should be centered on the object by rotating the body and not by turning the instrument in the hands. The instrument is correctly sighted when the center line in the mirror bisects both the image of the sight and the object sighted. When the instrument is thus sighted the reading of the needle will be comparatively easy, if the foregoing directions have been strictly complied with as to position, etc. The reading of the needle will then be the number of degrees and minutes that the object is to the east or west of a true north-south line passing through the center of the instrument. In order to save time, expert operators always take the mean of the needle vibrations as the reading, instead of waiting for the needle to come to rest.

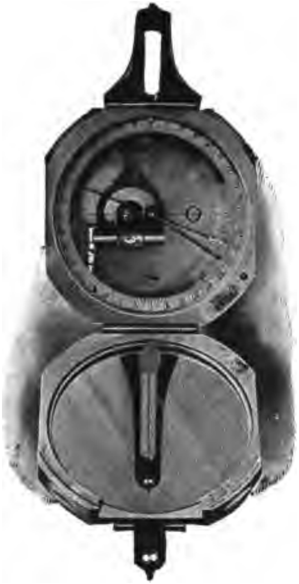

FIG. 31.—Operator's view when taking courses or horizontal angles. (Courtesy of Wm. Ainsworth & Sons.)

VERTICAL ANGLES.—"In taking vertical angles (see Figs. 32 and 33) the sighting bar is thrown out parallel with the face of the instrument, with the sighting end folded at right angles to the bar. Then the mirror lined lid is held at approximately an angle of 45° with the face of the instrument, in which position the eye can see through the opening in the end of the sighting bar, the cylindrical opening in the lid and

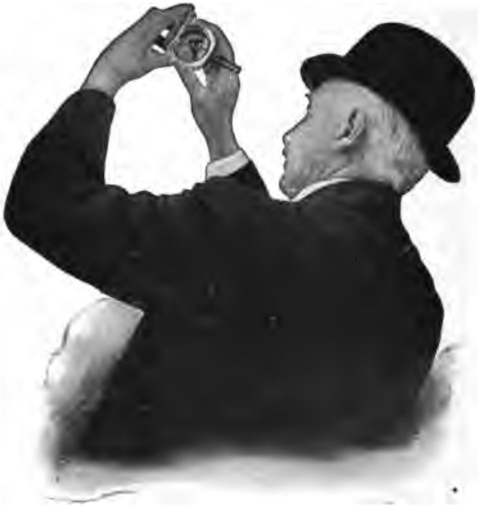

Fig. 32.—For vertical angles. (Courtesy of Wm. Ainsworth & Sons.)

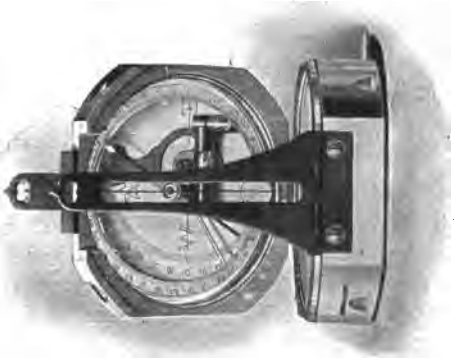

Fig. 33.—Operator's view of instrument when taking vertical angles. (Courtesy of Wm. Ainsworth & Sons.)

at the same time view the reflection of the large bubble tube in the mirror. Careful attention should be paid to the position of the hands, it being especially necessary that the thumb and forefinger of the right hand should grasp the body of the instrument while the middle finger moves the crank actuating the bubble tubes. Great care should be observed in taking vertical angles to be certain that the sides of the instrument are held perpendicular when the sight is taken, and at first it is well to repeat the sight two or three times in succession until the requsite degree of skill in handling is attained. The mirror cannot be used for the purpose of reading vertical angles, but is merely used to show the operator when the bubble is central, after which the lid is opened and the vernier arm read direct."

ADJUSTMENT OF THE BRUNTON.—When it is desired to use the Brunton in constructing an accurate map, in which declination is allowed for, it is necessary to secure the magnetic variation for the area to be mapped and then correct at each point where a reading is taken. This is the only adjustment necessary in using the Brunton and is best done as follows: Sight along some true north-south line as though reading a horizontal angle; then by turning the little adjustment screw on the side near the mirror, the compass circle may be rotated, either to the right or left, until the zero of the circle is exactly under the tip of the needle when thus sighted. The instrument is then adjusted for magnetic declination for the region in which the observation was taken and no correction is required when taking horizontal angles in the field.

The Aneroid Barometer. The aneroid is used by the field geologist for obtaining elevations when it is not desired to secure such accurate results as those given by the use of the telescopic alidade, or when it is desired to make a rapid survey of the area, and in the hands of a skilled operator this instrument has proved very accurate. There are several types of field aneroids, the most common of which is shown in Fig. 34.

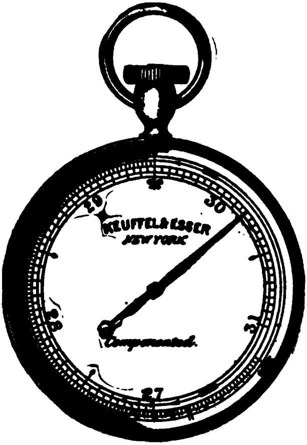

Fig. 34.—Aneroid Barometer. (Courtesy of Keuffel & Esser Co.)

In reading elevations with the barometer great care must be used to check frequently upon a bench mark, especially on days when the pressure conditions fluctuate rapidly. As a further check it is well to take readings on road and section corners, or other prominent points, where some later traverse will furnish a check on the readings.

By observing the following set of rules, and keeping a clear and concise set of notes made at the time of the readings, the aneroid may safely be used for securing elevations, and a reasonable degree of accuracy be expected.

Rules for the Use of the Aneroid.—1. Keep the instrument as near a uniform temperature as possible, since changes in temperature will cause fluctuations of the needle. Do not carry the aneroid first in one pocket and then in another; have one place for that purpose and keep the barometer there when not taking readings.

2. Avoid all unnecessary jolts, as they tend to injure the delicate mechanism of the instrument.

3. When reading elevations always hold the barometer with the dial horizontal and raise and lower the instrument about 3 feet, two or three times before reading. This will insure the needle being loosened and yet not jar the

more sensitive parts, as tapping the instrument is liable to do.

4. Keep a clear and concise set of notes and always record the time at which the reading was taken, for this is as important as the elevation reading. The following form for keeping notes has been found very satisfactory in many cases:

ANEROID NOTES

Station	Reading	Time	Correction	Elevation	Remarks
B.M. *A*	1000	9:00 A.M.	......	1000	N.W. cor. sec. 16
1	1026	9:15 A.M.	− 3′	1023	Elgin S.S.
2	1032	9:20 A.M.	− 4′	1028	Oread L.S.
3	1040	9:50 A.M.	−10′	1030	Oil well
B.M. *B*	1060	10:00 A.M.	−12′	1048	S.E. cor. sec. 16

From the above notes it is seen that after carrying elevations for one hour and then checking to B.M. *B* the aneroid reads 1060 feet, while the correct elevation at that point is 1048, making a total variation of 12 feet, or 1 foot for every 5 minutes. It is therefore necessary to subtract 1 foot for each 5 minutes after the first reading, and this is made from the readings in column 2 to give the correct elevations as shown in column 5.

ADJUSTMENTS OF THE ANEROID.—The adjustments of the barometer are too delicate to be made by the layman, and it is therefore best to send the instrument back to the factory when in need of adjustment.

The Stadia Hand Level. The hand level (Fig. 35) is a small, compact instrument chiefly used for carrying elevations or determining whether a rock outcrop is dipping or not. It is, in a way, a modification of the telescopic alidade or transit in that it can be mounted on a tripod and used for carrying levels in regions where the slopes are not too steep for level shots. This instrument is often used by geologists

Fig. 35.—Stadia handlevel. (Courtesy of Keuffel & Esser Co.)

for rapid traverse work, where only elevations are desired, in which case the method of using is illustrated in Fig. 36. The elevation of *A* is known and it is desired to determine the elevation of point *B*. By sighting through the hand level from *A* to *B* it is found that *B* is lower than *A*, and by

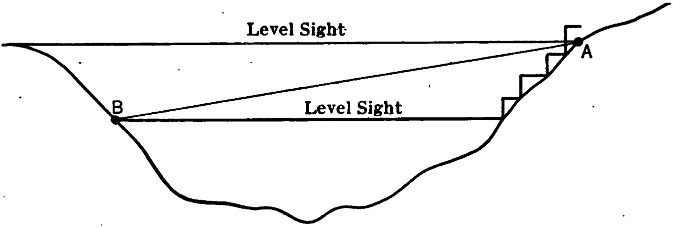

Fig. 36.—Method of carrying elevations with a stadia handlevel.

going down the slope at *A* and sighting at intervals on *B* a place is found where the eye is exactly on a level with that point. Then by turning the head and sighting through the level at the slope directly behind the operator a point is located which is likewise level with *B*. Walking up to this point and standing erect over it determine the next location up the slope that is level with the eye. By moving up to that and repeating the operation until the middle hair of the instrument comes just below or above point *A* the observer will have a certain number of intervals. Each of these intervals will be equal to the difference in elevation represented by the height from the observer's eye to the soles of the feet, and this distance when multiplied by the number of intervals ± the overlap at *A* will be the vertical distance that *B* is below *A*. Thus if the observer secures four intervals, each of which is equal to 5.3 feet, and finds that in the fourth interval the middle hair of the instrument, when held level, is 2 feet above point *A*, then the difference in elevation is 19.2 feet; $(4\times 5.3 \text{ feet}) - 2$ feet, the distance that *B* is below *A*.

Having ascertained the elevation of point *B* with reference to that of *A* it is then possible to go to *B* and in like manner determine the elevation of some other location, and by repeating this operation at successive points a very satisfactory line of elevations may be carried. This method of securing elevations is in general more accurate than the method of using the aneroid, and has the greater advantage in that it can be used on days when the aneroid will fluctuate too much for accurate work. The disadvantage of this method is that it can be used most successfully only in open country where the outcrops show up well, or where objects can be seen for some distance.

ADJUSTMENT OF THE LEVEL.—In using the stadia hand-level there is in general but one adjustment that will be found necessary, that of keeping the bubble uniform, and this adjustment is easily accomplished by the use of two pegs as illustrated in Fig. 37. When the instrument is leveled at *A*, drive a small peg in object *B* at the point where the middle hair intersects it and also mark the position of the center of the instrument at *A*. Then by leveling the tube of the instrument at *B* and sighting back to *A*, if the instrument is in correct adjustment the middle hair should intersect point *A* at the exact position formerly occupied by the center of the instrument.

When found necessary to adjust the bubble after testing in this manner it may be done by a few turns of the adjusting screw (*X*) and moving of the wedge (*Y*) either forward or back as found necessary until the bubble is in adjustment.

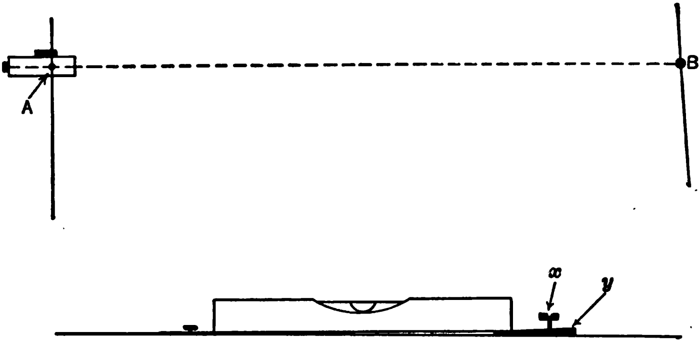

Fig. 37.—Manner of adjusting stadia bubble by use of two pegs (*A* & *B*).

If the stadia wires require adjustment the method described on page 67 should be used.

CHAPTER V

USEFUL TABLES AND MERIDIAN DETERMINATION

Determination of Meridian by Equal Altitudes of the Sun.—In accurate field mapping it is necessary that the maps show true direction and not merely magnetic. In order to do this it is necessary to establish a true meridian line, if one is not already given in the area.

Doubtless it will soon occur to anyone that if we have a line of sight to the sun in early morning and another in the late afternoon when the sun is at an altitude equal to that in the morning, it would be but a simple matter to bisect the angle between these two lines of sight and thus secure a true meridian. This is in general the method used but, due

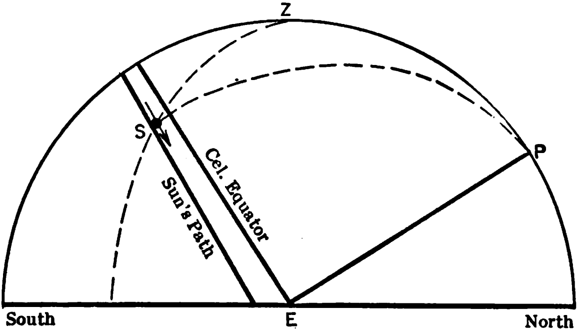

Fig. 38.—Showing sun's daily course and a few important points in the celestial sphere. (After Harris.)

to the fact that the sun is constantly changing in declination, there are correction factors to be applied.

In Fig. 38 is shown the path of the sun in early springtime. The declination is –, or south, but is decreasing as the path shows. If, on March 21, the sun rose exactly in the east, it would be several minutes above the Celestial Equator before noon; and in the afternoon, still more. Hence the necessity of modifying the observations as described above.

If the sun is moving toward the Celestial Equator, as shown in Fig. 38, it is obvious that the line of sight in the afternoon would be farther to the right from due south than in the morning. Therefore a mere bisection of the angle between the two does not establish a true meridian, unless correction be applied as follows: First find the sun's hourly change in declination (Table I); multiply this by the number of hours elapsed between the equal altitude morning and afternoon observations; divide this result by the product of the sine latitude and sine hour angles (one-half the time elapsed between the morning and afternoon observations, reduced to arc); the result will be the amount the afternoon observation must be moved to the left before bisecting the angle. If, for example, observations are taken on September 15, Lat. 42° 27′ N., at approximately 9 A. M. and 3 P. M., or times of equal altitude, which way and how far must one observation be moved in order that the line bisecting the angle between the two shall be a true meridian?

Here the sun's hourly change in declination is (Table I), $-58''$.

$-58''\times 6$ (No. hrs. between observations) $= -5.8'$;
one-half No. of hrs. reduced to arc (Table II) is 45°;
cos. lat. (42° 27′) is equal to .738;
sin $45° = .707$,

hence

cos lat. × sin (one-half time reduced to arc) = .522
$-5.8 \div .522 = 11.1'$ *Ans.*

Since the change in declination is minus, it is obvious that the western observation is too far to the left, or south, and accordingly must, in this instance, be moved 11.1′ northerly, or to the right.

In the taking of these observations there are two methods that may be used: First, after reading the observation on the sun, depress the telescope and set a stake directly in the line of sight, then secure the true meridian by moving one stake the correct amount and bisecting between the two. The other method is to use any distant well-defined terrestial object as a point of reference for measuring horizontal angles, or fixing the sun's azimuth at any given time. This point had best be chosen, in the northern hemisphere, to the left of the morning position of the sun.

If the sun's azimuth from the fixed point for the morning observation is a, and for the corrected afternoon observation is b; then $\frac{1}{2}(a+b)$ will be the angle to lay off from the point of reference to the meridian.

In the use of this method for meridian determination no observer should limit himself to one observation in the morning and one in the afternoon, but should make at least four separate sets—two with the telescope direct, and two reversed.

Determination of Meridian by Polaris.—It can easily be seen that were it possible to set a stake in the horizon, under Polaris at eastern and western elongation, and then bisect the angle between them, a correct meridian could be secured at once. But Polaris is rarely visible at both elongations during the same twenty-four hours, so some method must be employed to utilize observations made at one elongation only.

The farther one goes north from the equator the greater will be the horizontal angle between the bases of perpendiculars passing through Polaris at elongations. In Fig. 39, *Z* represents the zenith (a function of latitude); *P* represents the pole, while *E* and *W* show east and west elongations of Polaris, and *E′* and *W′* show the east and west elongation points on the horizon.

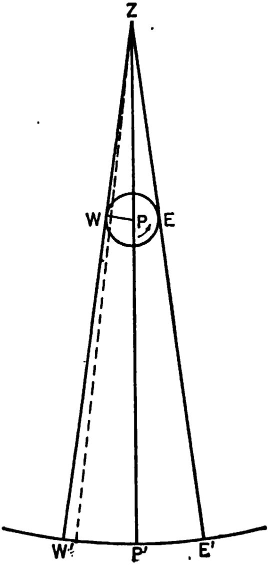

FIG. 39.—Showing diurnal motion of Polaris and positions at elongations. (After Harris.)

The relations in the triangle *WZP* are such that

$$R \sin WP \div \sin PZ = \sin WZP,$$

or

$$R \cos \delta \div \cos \phi = \sin \text{(zenith angle)}\ Z,$$

or

$$10 + \log \cos \delta - \log \cos \phi = \log \sin Z.$$

As an example of this method of meridian determination, note in Nautical Almanac, decl. Polaris, October 20, 1904, was 88° 47.9′. If a perpendicular line be dropped at western elongation, *W*, to the horizon at *W′*, how far west of due north, *N′*, is *W′*? First if latitude 29° N; second 42° 27′ N; and third 65° N.

$$\begin{array}{rl}
\text{Log cos } 88^\circ\ 47.9' = & 8.32163 \\
R = & 10.00000 \\
\text{Sum} = & \underline{18.32163} \\
-\log \cos 29^\circ = & \underline{\ 9.94182} \\
\text{Difference} = & 8.37981 = \log \sin 1^\circ\ 22.4' \\
\text{For Lat. } 42^\circ\ 27' & \qquad = \qquad 1^\circ\ 37.4' \\
\text{For Lat. } 65^\circ & \qquad = \qquad 2^\circ\ 50.4'
\end{array}$$

In the determination of meridian by observations on Polaris there are two things that must be known—the latitude and the declination, or Polar distance of Polaris. The latitude may generally be scaled off on the map to within 1′, if one can identify his exact location on the map, and when the exact location is not known, the latitude may be determined for these observations as described below. The declination may be obtained as follows:

Declination of Polaris....June—July....1914....88° 50.75′

Other months +	January	0.5′	August	0.1′
	February	0.5′	September	0.2′
	March	0.4′	October	0.4′
	April	0.2′	November	0.6′
	May	0.1′	December	0.75′

Annual change.................................+0.3′

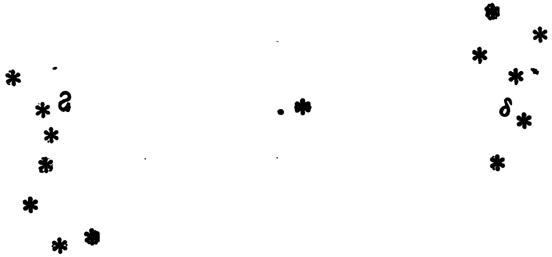

Fig. 40—Polaris (in center) at eastern elongation. (After Harris.)

As regards observations on Polaris, it is well to bear in mind that one must await a time when the E. and W. points in the horizon and δ, Polaris, and ζ lie in one great circle; or when δ Cassiopeia and ζ Ursa Major have approximately the same altitude as shown in Fig. 40. For it is then that Polaris is in a correct position for elongation observations. During the evening, in the fall, the elongation (Fig. 40) is at a convenient time for observing; in the spring the west elongation is most conveniently observed. To secure apparent relations for western elongation hold Fig. 40 upside down.

LATITUDE DETERMINATION.—When it becomes necessary to have correct latitude and it cannot be secured from a map it may be reckoned from a circumpolar star. It can easily be seen that in Fig. 40 the angular measurement of *P–P′* gives latitude. Since, however, there is nothing at *P* upon which to sight, the height of Polaris is taken, at either upper or lower culmination, and the polar distance subtracted or added. The result, after subtracting refraction, gives the latitude of the place of observation. Thus, if on November 1, 1914, the apparent altitude of Polaris was 47° 21.5′, the latitude of the station of observation is determined as follows:

Apparent altitude....................	47° 21.5′
Refraction (Table IV)................	.9′
True altitude.........................	47° 20.6′
Decl. (see page 81) is................	88° 51.3′
∴ Polar distance	1° 8.7′ (90°–88° 51.3′)
Latitude.............................	46° 11.9′

Thus the meridian and latitude may be determined for any area in which it is desired to do very accurate work, and where neither is known. For the purpose of making such observations as have been described a small transit is necessary.

TABLE I

SUN'S HOURLY CHANGE IN DECLINATION

Day of Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	+12	43	57	58	45	21	10	38	54	58	48	23
5	17	46	58	56	43	17	14	41	56	58	46	19
10	22	49	59	54	39	12	19	44	57	57	42	14
15	28	52	59	52	36	7	24	47	58	56	38	8
20	32	54	59	49	31	+ 2	28	49	58	54	34	− 2
25	37	56	59	47	27	− 4	32	52	59	52	30	+ 4
30	41	...	58	46	23	9	36	54	59	49	25	10

TABLE II

CONVERSION OF TIME INTO ARC[1]

Hours of Time into Arc

Time	Arc	Time	Arc	Time	Arc	Time	Arc	Time	Arc	Time	Arc
hrs.	°	*hrs.*	°	*hrs.*	°	*hrs.*	°	*hrs.*	°	*hrs.*	°
1	15	**5**	75	**9**	135	**13**	195	**17**	255	**21**	315
2	30	**6**	90	**10**	150	**14**	210	**18**	270	**22**	330
3	45	**7**	105	**11**	165	**15**	225	**19**	285	**23**	345
4	60	**8**	120	**12**	180	**16**	240	**20**	300	**24**	360

Minutes of Time into Arc

m.	° ′	m.	° ′	m.	° ′
1	0 15	**21**	5 15	**41**	10 15
2	0 30	22	5 30	42	10 30
3	0 45	23	5 45	43	10 45
4	1 0	24	6 0	44	11 0
5	1 15	**25**	6 15	**45**	11 15
6	1 30	26	6 30	46	11 30
7	1 45	27	6 45	47	11 45
8	2 0	28	7 0	48	12 0
9	2 15	29	7 15	49	12 15
10	2 30	**30**	7 30	**50**	12 30
11	2 45	31	7 45	51	12 45
12	3 0	32	8 0	52	13 0
13	3 15	33	8 15	53	13 15
14	3 30	34	8 30	54	13 30
15	3 45	**35**	8 45	**55**	13 45
16	4 0	36	9 0	56	14 0
17	4 15	37	9 15	57	14 15
18	4 30	38	9 30	58	14 30
19	4 45	39	9 45	59	14 45
20	5 0	**40**	10 0	**60**	15 0

Seconds of Time into Arc

s.	′ ″	s.	′ ″	s.	′ ″
1	0 15	**21**	5 15	**41**	10 15
2	0 30	22	5 30	42	10 30
3	0 45	23	5 45	43	10 45
4	1 0	24	6 0	44	11 0
5	1 15	**25**	6 15	**45**	11 15
6	1 30	26	6 30	46	11 30
7	1 45	27	6 45	47	11 45
8	2 0	28	7 0	48	12 0
9	2 15	29	7 15	49	12 15
10	2 30	**30**	7 30	**50**	12 30
11	2 45	31	7 45	51	12 45
12	3 0	32	8 0	52	13 0
13	3 15	33	8 15	53	13 15
14	3 30	34	8 30	54	13 30
15	3 45	**35**	8 45	**55**	13 45
16	4 0	36	9 0	56	14 0
17	4 15	37	9 15	57	14 15
18	4 30	38	9 30	58	14 30
19	4 45	39	9 45	59	14 45
20	5 0	**40**	10 0	**60**	15 0

Hundredths of a Second of Time into Arc

Hundredths of a Second of Time	**.00**	**.01**	**.02**	**.03**	**.04**	**.05**	**.06**	**.07**	**.08**	**.09**
s.	″	″	″	″	″	″	″	″	″	″
0.00	0.00	0.15	0.30	0.45	0.60	0.75	0.90	1.05	1.20	1.35
.10	1.50	1.65	1.80	1.95	2.10	2.25	2.40	2.55	2.70	2.85
.20	3.00	3.15	3.30	3.45	3.60	3.75	3.90	4.05	4.20	4.35
.30	4.50	4.65	4.80	4.95	5.10	5 25	5.40	5.55	5.70	5.85
.40	6.00	6.15	6.30	6.45	6.60	6.75	6.90	7.05	7.20	7.35
0.50	7.50	7.65	7.80	7.95	8.10	8.25	8.40	8.55	8.70	8.85
.60	9.00	9.15	9.30	9.45	9.60	9.75	9.90	10.05	10.20	10.35
.70	10.50	10.65	10.80	10.95	11.10	11.25	11.40	11.55	11.70	11.85
.80	12.00	12.15	12.30	12.45	12.60	12.75	12.90	13.05	13.20	13.35
.90	13.50	13.65	13.80	13.95	14.10	14.25	14.40	14.55	14.70	14.85

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[1] U. S. G. S. Bull. No. 650, Geographical Tables and Formulas, p. 125.

TABLE III

Conversion of Arc into Time[1]

°	h. m.	°	h. m.	°	h. m.	°	h. m.	°	h. m.	°	h. m.	′	m. s.	″	s.
0	0 0	**60**	4 0	**120**	8 0	**180**	12 0	**240**	16 0	**300**	20 0	**0**	0 0	**0**	0.000
1	0 4	61	4 4	121	8 4	181	12 4	241	16 4	301	20 4	1	0 4	1	0.067
2	0 8	62	4 8	122	8 8	182	12 8	242	16 8	302	20 8	2	0 8	2	0.133
3	0 12	63	4 12	123	8 12	183	12 12	243	16 12	303	20 12	3	0 12	3	0.200
4	0 16	64	4 16	124	8 16	184	12 16	244	16 16	304	20 16	4	0 16	4	0.267
5	0 20	**65**	4 20	**125**	8 20	**185**	12 20	**245**	16 20	**305**	20 20	**5**	0 20	**5**	0.333
6	0 24	66	4 24	126	8 24	186	12 24	246	16 24	306	20 24	6	0 24	6	0.400
7	0 28	67	4 28	127	8 28	187	12 28	247	16 28	307	20 28	7	0 28	7	0.467
8	0 32	68	4 32	128	8 32	188	12 32	248	16 32	308	20 32	8	0 32	8	0.533
9	0 36	69	4 36	129	8 36	189	12 36	249	16 36	309	20 36	9	0 36	9	0.600
10	0 40	**70**	4 40	**130**	8 40	**190**	12 40	**250**	16 40	**310**	20 40	**10**	0 40	**10**	0.667
11	0 44	71	4 44	131	8 44	191	12 44	251	16 44	311	20 44	11	0 44	11	0.733
12	0 48	72	4 48	132	8 48	192	12 48	252	16 48	312	20 48	12	0 48	12	0.800
13	0 52	73	4 52	133	8 52	193	12 52	253	16 52	313	20 52	13	0 52	13	0.867
14	0 56	74	4 56	134	8 56	194	12 56	254	16 56	314	20 56	14	0 56	14	0.933
15	1 0	**75**	5 0	**135**	9 0	**195**	13 0	**255**	17 0	**315**	21 0	**15**	1 0	**15**	1.000
16	1 4	76	5 4	136	9 4	196	13 4	256	17 4	316	21 4	16	1 4	16	1.067
17	1 8	77	5 8	137	9 8	197	13 8	257	17 8	317	21 8	17	1 8	17	1.133
18	1 12	78	5 12	138	9 12	198	13 12	258	17 12	318	21 12	18	1 12	18	1.200
19	1 16	79	5 16	139	9 16	199	13 16	259	17 16	319	21 16	19	1 16	19	1.267
20	1 20	**80**	5 20	**140**	9 20	**200**	13 20	**260**	17 20	**320**	21 20	**20**	1 20	**20**	1.333
21	1 24	81	5 24	141	9 24	201	13 24	261	17 24	321	21 24	21	1 24	21	1.400
22	1 28	82	5 28	142	9 28	202	13 28	262	17 28	322	21 28	22	1 28	22	1.467
23	1 32	83	5 32	143	9 32	203	13 32	263	17 32	323	21 32	23	1 32	23	1.533
24	1 36	84	5 36	144	9 36	204	13 36	264	17 36	324	21 36	24	1 36	24	1.600
25	1 40	**85**	5 40	**145**	9 40	**205**	13 40	**265**	17 40	**325**	21 40	**25**	1 40	**25**	1.667
26	1 44	86	5 44	146	9 44	206	13 44	266	17 44	326	21 44	26	1 44	26	1.733
27	1 48	87	5 48	147	9 48	207	13 48	267	17 48	327	21 48	27	1 48	27	1.800
28	1 52	88	5 52	148	9 52	208	13 52	268	17 52	328	21 52	28	1 52	28	1.867
29	1 56	89	5 56	149	9 56	209	13 56	269	17 56	329	21 56	29	1 56	29	1.933

30	2	0	90	6	0	150	10	0	210	14	0	270	18	0	330	22	0	30	2	0	30	2.000
31	2	4	91	6	4	151	10	4	211	14	4	271	18	4	331	22	4	31	2	4	31	2.067
32	2	8	92	6	8	152	10	8	212	14	8	272	18	8	332	22	8	32	2	8	32	2.133
33	2	12	93	6	12	153	10	12	213	14	12	273	18	12	333	22	12	33	2	12	33	2.200
34	2	16	94	6	16	154	10	16	214	14	16	274	18	16	334	22	16	34	2	16	34	2.267
35	2	20	95	6	20	155	10	20	215	14	20	275	18	20	335	22	20	35	2	20	35	2.333
36	2	24	96	6	24	156	10	24	216	14	24	276	18	24	336	22	24	36	2	24	36	2.400
37	2	28	97	6	28	157	10	28	217	14	28	277	18	28	337	22	28	37	2	28	37	2.467
38	2	32	98	6	32	158	10	32	218	14	32	278	18	32	338	22	32	38	2	32	38	2.533
39	2	36	99	6	36	159	10	36	219	14	36	279	18	36	339	22	36	39	2	36	39	2.600
40	2	40	100	6	40	160	10	40	220	14	40	280	18	40	340	22	40	40	2	40	40	2.667
41	2	44	101	6	44	161	10	44	221	14	44	281	18	44	341	22	44	41	2	44	41	2.733
42	2	48	102	6	48	162	10	48	222	14	48	282	18	48	342	22	48	42	2	48	42	2.800
43	2	52	103	6	52	163	10	52	223	14	52	283	18	52	343	22	52	43	2	52	43	2.867
44	2	56	104	6	56	164	10	56	224	14	56	284	18	56	344	22	56	44	2	56	44	2.933
45	3	0	105	7	0	165	11	0	225	15	0	285	19	0	345	23	0	45	3	0	45	3.000
46	3	4	106	7	4	166	11	4	226	15	4	286	19	4	346	23	4	46	3	4	46	3.067
47	3	8	107	7	8	167	11	8	227	15	8	287	19	8	347	23	8	47	3	8	47	3.133
48	3	12	108	7	12	168	11	12	228	15	12	288	19	12	348	23	12	48	3	12	48	3.200
49	3	16	109	7	16	169	11	16	229	15	16	289	19	16	349	23	16	49	3	16	49	3.267
50	3	20	110	7	20	170	11	20	230	15	20	290	19	20	350	23	20	50	3	20	50	3.333
51	3	24	111	7	24	171	11	24	231	15	24	291	19	24	351	23	24	51	3	24	51	3.400
52	3	28	112	7	28	172	11	28	232	15	28	292	19	28	352	23	28	52	3	28	52	3.467
53	3	32	113	7	32	173	11	32	233	15	32	293	19	32	353	23	32	53	3	32	53	3.533
54	3	36	114	7	36	174	11	36	234	15	36	294	19	36	354	23	36	54	3	36	54	3.600
55	3	40	115	7	40	175	11	40	235	15	40	295	19	40	355	23	40	55	3	40	55	3.667
56	3	44	116	7	44	176	11	44	236	15	44	296	19	44	356	23	44	56	3	44	56	3.733
57	3	48	117	7	48	177	11	48	237	15	48	297	19	48	357	23	48	57	3	48	57	3.800
58	3	52	118	7	52	178	11	52	238	15	52	298	19	52	358	23	52	58	3	52	58	2.867
59	3	56	119	7	56	179	11	56	239	15	56	299	19	56	359	23	56	59	3	56	59	3.933
60	4	0	120	8	0	180	12	0	240	16	0	300	20	0	360	24	0	60	4	0	60	4.000

Multiply degrees, minutes, and seconds of arc separately by 4; the products will be minutes, seconds, and sixtieths of seconds of time.

[1] U. S. G. S. Bull No. 650, Geographic Tables and Formulas, p. 124.

TABLE IV

Mean Refraction[1]

Apparent Altitude	Refraction		Apparent Altitude	Refraction		Apparent Altitude	Refraction	
° ′	′ ″	″	° ′	′ ″	″	° ′	′ ″	″
0 0	34 54.1		6 0	8 23.3		12 0	4 25.0	
10	32 49.2	124.9	10	8 11.6	11.7	10	4 21.4	3.6
20	30 52.3	116.9	20	8 0.3	11.3	20	4 18.0	3.4
30	29 3.5	108.8	30	7 49.5	10.8	30	4 14.6	3.4
40	27 22.7	100.8	40	7 39.2	10.3	40	4 11.3	3.3
50	25 49.8	92.9	50	7 29.2	10.0	50	4 8.1	3.2
1 0	24 24.6	85.2	7 0	7 19.7	9.5	13 0	4 4.9	3.2
10	23 6.7	77.9	10	7 10.5	9.2	10	4 1.8	3.1
20	21 55 6.	71.1	20	7 1.7	8.8	20	3 58.8	3.0
30	20 50.9	64.7	30	6 53.3	8.4	30	3 55.9	2.9
40	19 51.9	59.0	40	6 45.1	8.2	40	3 53.0	2.9
50	18 58.0	53.9	50	6 37.2	7.9	50	3 50.2	2.8
2 0	18 8.6	49.4	8 0	6 29.6	7.6	14 0	3 47.4	2.8
10	17 23.0	45.6	10	6 22.3	7.3	20	3 42.1	5.3
20	16 40.7	42.3	20	6 15.2	7.1	40	3 37.0	5.1
30	16 0.9	39.8	30	6 8.4	6.8	15 0	3 32.1	4.9
40	15 23.4	37.5	40	6 1.8	6.6	20	3 27.4	4.7
50	14.47.8	35.6	50	5 55.4	6.4	40	3 22.9	4.5
3 0	14 14.6	33.2	9 0	5 49.3	6.1	16 0	3 18.6	4.3
10	13 43.7	30.9	10	5.43.3	6.0	20	2 14.5	4.1
20	13 15.0	28.7	20	5 37.6	5.7	40	3 10.5	4.0
30	12 48.3	26.7	30	5 32.0	5.6	17 0	3 6.6	3.9
40	12 23.7	24.6	40	5 26.5	5.5	20	3 2.9	3.7
50	12 0.7	23.0	50	5 21.3	5.2	40	2 59.3	3.6
4 0	11 38.9	21.8	10 0	5 16.2	5.1	18 0	2 55.8	3.5
10	11 18.3	20.6	10	5 11.2	5.0	20	2 52.5	3.3
20	10 58.6	19.7	20	5 6.4	4.8	40	2 49.3	3.2
30	10 39.6	19.0	30	5 1.7	4.7	19 0	2 46.1	3.2
40	10 21.2	18.4	40	4 57.2	4.5	20	2 43.1	3.0
50	10 3.3	17.9	50	4 52.8	4.4	40	2 40.2	2.9
5 0	9 46.5	16.8	11 0	4 48.5	4.3	20 0	2 37.3	2.9
10	9 30.9	15.6	10	4 44.3	4.2	20	2 34.5	2.8
20	9 16.0	14.9	20	4 40.2	4.1	40	2 31.9	2.6
30	9 1.9	14.1	30	4 36.3	3.9	21 0	2 29.3	2.6
40	8.48.4	13.5	40	4 32.4	3.9			
50	8 35.6	12.8	50	4 28.7	3.7			
6 0	8 23.3	12.3	12 0	4 25.0	3.7			

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[1] U. S. G. S. Bull. No. 650, Geographic Tables and Formulas, page 334.

TABLE IV—*Continued*

Apparent Altitude	Refraction		Apparent Altitude	Refraction		Apparent Altitude	Refraction	
° ′	′ ″	″	° ′	′ ″	″	° ′	′ ″	″
21 0	2 29.3	2.5	33 0	1 28.7	1.1	50	48.4	1.7
20	2 26.8	2.5	20	1 27.6	1.1	51	46.7	1.6
40	2 24.3	2.4	40	1 26.5	1.1	52	45.1	1.6
22 0	2 21.9	2.3	34 0	1 25.4	1.1	53	43.5	1.6
20	2 19.6	2.2	20	1 24.3	1.0	54	41.9	1.5
40	1 17.4	2.2	40	1 23.3	1.0	55	40.4	1.5
23 0	2 15.2	2.2	35 0	1 22.3	1.0	56	38.9	1.4
20	2 13.0	2.1	20	1 21.3	1.0	57	37.5	1.4
40	2 10.9	2.0	40	1 20.3	1.0	58	36.1	1.4
24 0	2 8.9	1.9	36 0	1 19.3	1.0	59	34.7	1.4
20	2 7.0	1.9	20	1 18.3	0.9	60	33.3	1.3
40	2 5.1	1.9	40	1 17.4	0.9	61	32.0	1.3
25 0	2 3.2	1.8	37 0	1 16.5	0.9	62	30.7	1.3
20	2 1.4	1.8	20	1 15.6	0.9	63	29.4	1.2
40	1 59.6	1.8	40	1 14.7	0.9	64	28.2	1.3
26 0	1 57.8	1.7	38 0	1 13.8	0.9	65	26.9	1.2
20	1 56.1	1.7	20	1 12.9	0.9	66	25.7	1.2
40	1 54.4	1.6	40	1 12.0	0.8	67	24.5	1.2
27 0	1 52.8	1.6	39 0	1 11.2	0.9	68	23.3	1.1
20	1 51.2	1.5	20	1 10.3	0.8	69	22.2	1.2
40	1 49.7	1.5	40	1 9.5	0.8	70	21.0	1.1
28 0	1 48.2	1.5	40 0	1 8.7	0.8	71	19.9	1.1
20	1 46.7	1.4	20	1 7.9	0.8	72	18.8	1.1
40	1 45.3	1.5	40	1 7.1	0.8	73	17.7	1.1
29 0	1 43.8	1.4	41 0	1 6.3	0.8	74	16.6	1.1
20	1 42.4	1.4	20	1 5.5	0.8	75	15.5	1.0
40	1 41.0	1.3	40	1 4.7	0.7	76	14.5	1.1
30 0	1 39.7	1.3	42 0	1 4.0		77	13.4	1.1
20	1 38.4	1.3	42	64.0	2.2	78	12.3	1.1
40	1 37.1	1.3	43	61.8	2.1	79	11.2	1.0
31 0	1 35.8	1.3	44	59.7	2.0	80	10.2	1.1
20	1 34.5	1.2	45	57.7	2.0	81	9.1	1.0
40	1 33.3	1.2	46	55.7	1.9	82	8.1	4.0
32 0	1 32.1	1.2	47	53.8	1.9	86	4.1	4.1
20	1 30.9	1.1	48	51.9	1.7	90	0.0	
40	1 29.8	1.1	49	50.2	1.8			
33 0	1 28.7		50	48.4				

For altitudes 10° to 90° the approximate refraction in minutes equals the natural cotangent of the altitude.

TABLE V

CORRECTIONS FOR CURVATURE AND REFRACTION, IN FEET = 9.574 (DISTANCE MILES)^2

[Difference in feet between the apparent and true level at distances varying from 1 to 66 miles]

Distance, miles	Difference in Feet for			Distance, miles	Difference in Feet for		
	Curvature	Refraction	Curvature and Refraction		Curvature	Refraction	Curvature and Refraction
1	0.7	0.1	0.6	34	771.3	108.0	663.3
2	2.7	0.4	2.3	35	817.4	114.4	703.0
3	6.0	0.8	5.2	36	864.8	121.1	743.7
4	10.7	1.5	9.2	37	913.5	127.9	785.6
5	16.7	2.3	14.4	38	963.5	134.9	828.6
6	24.0	3.4	20.6	39	1014.9	142.1	872.8
7	32.7	4.6	28.1	40	1067.6	149.5	918.1
8	42.7	6.0	36.7	41	1121.7	157.0	964.7
9	54.0	7.6	46.4	42	1177.0	164.8	1012.2
10	66.7	9.3	57.4	43	1233.7	172.7	1061.0
11	80.7	11.3	69.4	44	1291.8	180.8	1111.0
12	96.1	13.4	82.7	45	1351.2	189.2	1162.0
13	112.8	15.8	97.0	46	1411.9	197.7	1214.2
14	130.8	18.3	112.5	47	1474.0	206.3	1267.7
15	150.1	21.0	129.1	48	1537.3	215.2	1322.1
16	170.8	23.9	146.9	49	1602.0	224.3	1377.7
17	192.8	27.0	165.8	50	1668.1	233.5	1434.6
18	216.2	30.3	185.9	51	1735.5	243.0	1492.5
19	240.9	33.7	207.2	52	1804.2	252.6	1551.6
20	266.9	37.4	229.5	53	1874.3	262.4	1611.9
21	294.3	41.2	253.1	54	1945.7	272.4	1673.3
22	322.9	45.2	277.7	55	2018.4	282.6	1735.8
23	353.0	49.4	303.6	56	2092.5	292.9	1799.6
24	384.3	53.8	330.5	57	2167.9	303.5	1864.4
25	417.0	58.4	358.6	58	2244.6	314.2	1930.4
26	451.1	63.1	388.0	59	2322.7	325.2	1997.5
27	486.4	68.1	418.3	60	2402.1	336.3	2065.8
28	523.1	73.2	449.9	61	2482.8	347.6	2135.2
29	561.2	78.6	482.6	62	2564.9	359.1	2205.8
30	600.5	84.1	516.4	63	2648.3	370.8	2277.5
31	641.2	89.8	551.4	64	2733.0	382.6	2350.4
32	683.3	95.7	587.6	65	2819.1	394.7	2424.4
33	726.6	101.7	624.9	66	2906.5	406.9	2499.6

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[1] U. S. G. S. Bull No. 650, Geographic Tables and Formulas, page 335.

TABLE VI

EQUIVALENTS: METERS—FEET

.00		.30		.60		.90	
Meters	Feet	Meters	Feet	Meters	Feet	Meters	Feet
0.00	0.00	0.30	0.98	0.60	1.97	0.90	2.95
0.01	0.03	0.31	1.02	0.61	2.00	0.91	2.98
0.02	0.07	0.32	1.05	0.62	2.03	0.92	3.02
0.03	0.10	0.33	1.08	0.63	2.07	0.93	3.05
0.04	0.13	0.34	1.12	0.64	2.10	0.94	3.08
0.05	0.16	0.35	1.15	0.65	2.13	0.95	3.12
0.06	0.20	0.36	1.18	0.66	2.17	0.96	3.15
0.07	0.23	0.37	1.21	0.67	2.20	0.97	3.18
0.08	0.26	0.38	1.25	0.68	2.23	0.98	3.22
0.09	0.30	0.39	1.28	0.69	2.26	0.99	3.25
0.10	0.33	0.40	1.31	0.70	2.30	1.00	3.28
0.11	0.36	0.41	1.35	0.71	2.33	1.01	3.31
0.12	0.39	0.42	1.38	0.72	2.36	1.02	3.35
0.13	0.43	0.43	1.41	0.73	2.39	1.03	3.38
0.14	0.46	0.44	1.44	0.74	2.43	1.04	3.41
0.15	0.49	0.45	1.48	0.75	2.46	1.05	3.45
0.16	0.53	0.46	1.51	0.76	2.49	1.06	3.48
0.17	0.56	0.47	1.54	0.77	2.53	1.07	3.51
0.18	0.59	0.48	1.57	0.78	2.56	1.08	3.54
0.19	0.62	0.49	1.61	0.79	2.59	1.09	3.58
0.20	0.66	0.50	1.64	0.80	2.62	1.10	3.61
0.21	0.69	0.51	1.67	0.81	2.66	1.11	3.64
0.22	0.72	0.52	1.71	0.82	2.69	1.12	3.68
0.23	0.75	0.53	1.74	0.83	2.72	1.13	3.71
0.24	0.79	0.54	1.77	0.84	2.76	1.14	3.74
0.25	0.82	0.55	1.80	0.85	2.79	1.15	3.77
0.26	0.85	0.56	1.84	0.86	2.82	1.16	3.81
0.27	0.89	0.57	1.87	0.87	2.85	1.17	3.84
0.28	0.92	0.58	1.90	0.88	2.89	1.18	3.87
0.29	0.95	0.59	1.94	0.89	2.92	1.19	3.90

TABLE VI—*Continued*

1.20		1.52		1.81		2.16	
Meters	**Feet**	**Meters**	**Feet**	**Meters**	**Feet**	**Meters**	**Feet**
1.20	3.94	1.52	4.99	1.84	6.04	2.16	7.09
1.21	3.97	1.53	5.02	1.85	6.07	2.17	7.12
1.22	4.00	1.54	5.05	1.86	6.10	2.18	7.15
1.23	4.03	1.55	5.08	1.87	6.14	2.19	7.19
1.24	4.07	1.56	5.12	1.88	6.17	2.20	7.22
1.25	4.10	1.57	5.15	1.89	6.20	2.21	7.25
1.26	4.13	1.58	5.18	1.90	6.23	2.22	7.28
1.27	4.17	1.59	5.22	1.91	6.27	2.23	7.32
1.28	4.20	1.60	5.25	1.92	6.30	2.24	7.35
1.29	4.23	1.61	5.28	1.93	6.33	2.25	7.38
1.30	4.27	1.62	5.32	1.94	6.37	2.26	7.41
1.31	4.30	1.63	5.35	1.95	6.40	2.27	7.45
1.32	4.33	1.64	5.38	1.96	6.43	2.28	7.48
1.33	4.36	1.65	5.41	1.97	6.46	2.29	7.51
1.34	4.40	1.66	5.45	1.98	6.50	2.30	7.55
1.35	4.43	1.67	5.48	1.99	6.53	2.31	7.58
1.36	4.46	1.68	5.51	2.00	6.56	2.32	7.61
1.37	4.50	1.69	5.54	2.01	6.59	2.33	7.65
1.38	4.53	1.70	5.58	2.02	6.63	2.34	7.68
1.39	4.56	1.71	5.61	2.03	6.66	2.35	7.71
1.40	4.59	1.72	5.64	2.04	6.69	2.36	7.74
1.41	4.63	1.73	5.68	2.05	6.72	2.37	7.78
1.42	4.66	1.74	5.71	2.06	6.76	2.38	7.81
1.43	4.69	1.75	5.74	2.07	6.79	2.39	7.84
1.44	4.72	1.76	5.77	2.08	6.82	2.40	7.87
1.45	4.76	1.77	5.81	2.09	6.86	2.41	7.91
1.46	4.79	1.78	5.84	2.10	6.89	2.42	7.94
1.47	4.82	1.79	5.87	2.11	6.92	2.43	7.97
1.48	4.86	1.80	5.91	2.12	6.97	2.44	8.01
1.49	4.89	1.81	5.94	2.13	6.99	2.45	8.04
1.50	4.92	1.82	5.97	2.14	7.02	2.46	8.07
1.51	4.95	1.83	6.00	2.15	7.05	2.47	8.10

TABLE VI—*Continued*

2.48		2.80		3.12		3.44	
Meters	**Feet**	**Meters**	**Feet**	**Meters**	**Feet**	**Meters**	**Feet**
2.48	8.14	2.80	9.19	3.12	10.24	3.44	11.29
2.49	8.17	2.81	9.22	3.13	10.27	3.45	11.32
2.50	8.20	2.82	9.25	3.14	10.30	3.46	11.35
2.51	8.24	2.83	9.29	3.15	10.33	3.47	11.39
2.52	8.27	2.84	9.32	3.16	10.37	3.48	11.42
2.53	8.30	2.85	9.35	3.17	10.40	3.49	11.45
2.54	8.33	2.86	9.39	3.18	10.43	3.50	11.48
2.55	8.37	2.87	9.42	3.19	10.47	3.51	11.52
2.56	8.40	2.88	9.45	3.20	10.50	3.52	11.55
2.57	8.43	2.89	9.48	3.21	10.53	3.53	11.58
2.58	8.46	2.90	9.51	3.22	10.56	3.54	11.61
2.59	8.50	2.91	9.55	3.23	10.60	3.55	11.65
2.60	8.53	2.92	9.58	3.24	10.63	3.56	11.68
2.61	5.56	2.93	9.61	3.25	10.66	3.57	11.71
2.62	8.60	2.94	9.65	3.26	10.70	3.58	11.75
2.63	8.63	2.95	9.68	3.27	10.73	3.59	11.78
2.64	8.66	2.96	9.71	3.28	10.76	3.60	11.81
2.65	8.69	2.97	9.75	3.29	10.79	3.61	11.84
2.66	8.73	2.98	9.78	3.30	10.83	3.62	11.88
2.67	8.76	2.99	9.81	3.31	10.86	3.63	11.91
2.68	8.79	3.00	9.84	3.32	10.89	3.64	11.94
2.69	8.83	3.01	9.88	3.33	10.93	3.65	11.98
2.70	8.86	3.02	9.91	3.34	10.96	3.66	12.01
2.71	8.89	3.03	9.94	3.35	10.99	3.67	12.04
2.72	8.92	3.04	9.97	3.36	11.02	3.68	12.07
2.73	8.96	3.05	10.01	3.37	11.06	3.69	12.11
2.74	8.99	3.06	10.04	3.38	11.09	3.70	12.14
2.75	9.02	3.07	10.07	3.39	11.12	3.71	12.17
2.76	9.05	3.08	10.11	3.40	11.16	3.72	12.20
2.77	9.09	3.09	10.14	3.41	11.19	3.73	12.24
2.78	9.12	3.10	10.17	3.42	11.22	3.74	12.27
2.79	9.15	3.11	10.20	3.43	11.25		

TABLE VI—*Continued*

3.75		3.89		4.03		4.17	
Meters	Feet	Meters	Feet	Meters	Feet	Meters	Feet
3.75	12.30	3.88	12.73	4.01	13.16	4.14	13.58
3.76	12.34	3.89	12.76	4.02	13.19	4.15	13.62
3.77	12.37	3.90	12.80	4.03	13.22	4.16	13.65
3.78	12.40	3.91	12.83	4.04	13.26	4.17	13.68
3.79	12.43	3.92	12.86	4.05	13.29	4.18	13.71
3.80	12.47	3.93	12.89	4.06	13.32	4.19	13.75
3.81	12.50	3.94	12.93	4.07	13.35	4.20	13.78
3.82	12.53	3.95	12.96	4.08	13.39	4.21	13.81
3.83	12.57	3.96	12.99	4.09	13.42	4.22	13.85
3.84	12.60	3.97	13.02	4.10	13.45	4.23	13.88
3.85	12.63	3.98	13.06	4.11	13.48	4.24	13.91
3.86	12.66	3.99	13.09	4.12	13.52	4.25	13.94
3.87	12.70	4.00	13.12	4.13	13.55	4.26	13.98

TABLE VII

NUMBER OF RODS IN FEET AND INCHES

Rods	Feet	Inches	Rods	Feet	Inches	Rods	Feet	Inches
1	16	6	35	577	6	68	1122	0
2	33	0	36	594	0	69	1138	6
3	49	6	37	610	6	70	1155	0
4	66	0	38	627	0	71	1171	6
5	82	6	39	643	6	72	1188	0
6	99	0	40	660	0	73	1204	6
7	115	6	41	676	6	74	1221	0
8	132	0	42	693	0	75	1237	6
9	148	6	43	709	6	76	1254	0
10	165	0	44	726	0	77	1270	6
11	181	6	45	742	6	78	1287	0
12	198	0	46	759	0	79	1303	6
13	214	6	47	775	6	80	1320	0
14	231	0	48	792	0	81	1336	6
15	247	6	49	808	6	82	1353	0
16	264	0	50	825	0	83	1369	6
17	280	6	51	841	6	84	1386	0
18	297	0	52	858	0	85	1402	6
19	313	6	53	874	6	86	1419	0
20	330	0	54	891	0	87	1435	6
21	346	6	55	907	6	88	1452	0
22	363	0	56	924	0	89	1468	6
23	379	6	57	940	6	90	1485	0
24	396	0	58	957	0	91	1501	6
25	412	6	59	973	6	92	1518	0
26	429	0	60	990	0	93	1534	6
27	445	6	61	1006	6	94	1551	0
28	462	0	62	1023	0	95	1567	6
29	478	6	63	1039	6	96	1584	0
30	495	0	64	1056	0	97	1600	6
31	511	6	65	1072	6	98	1617	0
32	528	0	66	1089	0	99	1633	6
33	544	6	67	1105	6	100	1650	0
34	561	0						

TABLE VIII

NUMBER OF LINKS IN FEET AND INCHES

Links	Feet	Inches	Links	Feet	Inches	Links	Feet	Inches
1	0	7.92	35	23	1.20	68	44	10.56
2	1	3.84	36	23	9.12	69	45	6.48
3	1	11.76	37	24	5.04	70	46	2.40
4	2	7.68	38	25	0.96	71	46	10.32
5	3	3.60	39	25	8.88	72	47	6.24
6	3	11.52	40	26	4.80	73	48	2.16
7	4	7.44	41	27	0.72	74	48	10.08
8	5	3.36	42	27	8.64	75	49	6.00
9	5	11.28	43	28	4.56	76	50	1.92
10	6	7.20	44	29	0.48	77	50	9.84
11	7	3.12	45	29	8.40	78	51	5.76
12	7	11.04	46	30	4.32	79	52	1.68
13	8	6.96	47	31	0.24	80	52	9.60
14	9	2.88	48	31	8.16	81	53	5.52
15	9	10.80	49	32	4.08	82	54	1.44
16	10	6.72	50	33	0.00	83	54	9.36
17	11	2.64	51	33	7.92	84	55	5.28
18	11	10.56	52	34	3.84	85	56	1.20
19	12	6.48	53	34	11.76	86	56	9.12
20	13	2.40	54	35	7.68	87	57	5.04
21	13	10.32	55	36	3.60	88	58	0.96
22	14	6.24	56	36	11.52	89	58	8.88
23	15	2.16	57	37	7.44	90	59	4.80
24	15	10.08	58	38	3.36	91	60	0.72
25	16	6.00	59	38	11.28	92	60	8.64
26	17	1.92	60	39	7.20	93	61	4.56
27	17	9.84	61	40	3.12	94	62	0.48
28	18	5.76	62	40	11.04	95	62	8.40
29	19	1.68	63	41	6.96	96	63	4.32
30	19	9.60	64	42	2.88	97	64	0.24
31	20	5.52	65	42	10.80	98	64	8.16
32	21	1.44	66	43	6.72	99	65	4.08
33	21	9.36	67	44	2.64	100	66	0.00
34	22	5.28						

TABLE IX

SOLUTION OF RIGHT TRIANGLES

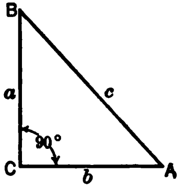
Given	Required	Formulæ
a, A	B, b, c	$B=90°-A$ $b=a \cot A$ $c=a \csc A$ 
a, B	A, b, c	$A=90°-B$ $b=a \tan B$ $c=a \sec B$
c, A	B, a, b	$B=90°-A$ $a=c \sin A$ $b=c \cos A$
a, b	A, B, c	$B=90°-A$. Tan $A=\frac{a}{b}$. Tan $B=\frac{b}{a}$ $c=\sqrt[2]{a^2+b^2}$ $c=a \csc A$
a, c	A, B, b	$\sin A=\frac{a}{c}$ $\cos B=\frac{a}{c}$ $b=\sqrt[2]{c^2-a^2}$ $b=a \cot A$

TABLE X

STADIA CONVERSION TABLE

′	0°	1°	2°	3°	4°	5°	6°	7°	8°
0	.00	1.74	3.49	5.23	6.96	8.68	10.40	12.10	13.78
2	.06	1.80	3.55	5.28	7.02	8.74	10.45	12.15	13.84
4	.12	1.86	3.60	5.34	7.07	8.80	10.51	12.21	13.89
6	.17	1.92	3.66	5.40	7.13	8.85	10.57	12.26	13.95
8	.23	1.98	3.72	5.46	7.19	8.91	10.62	12.32	14.01
10	.29	2.04	3.78	5.52	7.25	8.97	10.68	12.38	14.06
12	.35	2.09	3.84	5.57	7.30	9.03	10.74	12.43	14.12
14	.41	2.15	3.90	5.63	7.36	9.08	10.79	12.49	14.17
16	.47	2.21	3.95	5.69	7.42	9.14	10.85	12.55	14.23
18	.52	2.27	4.01	5.75	7.48	9.20	10.91	12.60	14.28
20	.58	2.33	4.07	5.80	7.53	9.25	10.96	12.66	14.34
22	.64	2.38	4.13	5.86	7.59	9.31	11.02	12.72	14.40
24	.70	2.44	4.18	5.92	7.65	9.37	11.08	12.77	14.45
26	.76	2.50	4.24	5.98	7.71	9.43	11.13	12.83	14.51
28	.81	2.56	4.30	6.04	7.76	9.48	11.19	12.88	14.56
30	.87	2.62	4.36	6.09	7.82	9.54	11.25	12.94	14.62
32	.93	2.67	4.42	6.15	7.88	9.60	11.30	13.00	14.67
34	.99	2.73	4.48	6.21	7.94	9.65	11.36	13.05	14.73
36	1.05	2.79	4.53	6.27	7.99	9.71	11.42	13.11	14.79
38	1.11	2.85	4.59	6.33	8.05	9.77	11.47	13.17	14.84
40	1.16	2.91	4.65	6.38	8.11	9.83	11.53	13.22	14.90
42	1.22	2.97	4.71	6.44	8.17	9.88	11.59	13.28	14.95
44	1.28	3.02	4.76	6.50	8.22	9.94	11.64	13.33	15.01
46	1.34	3.08	4.82	6.56	8,28	10.00	11.70	13.39	15.06
48	1.40	3.14	4.88	6.61	8.34	10.05	11.76	13.45	15.12
50	1.45	3.20	4.94	6.67	8.40	10.11	11.81	13.50	15.17
52	1.51	3.26	4.99	6.73	8.45	10.17	11.87	13.56	15.23
54	1.57	3.31	5.05	6.78	8.51	10.22	11.93	13.61	15.28
56	1.63	3.37	5.11	6.84	8.57	10.28	11.98	13.67	15.34
58	1.69	3.43	5.17	6.90	8.63	10.34	12.04	13.73	15.40
60	1.74	3.49	5.23	6.96	8.68	10.40	12.10	13.78	15.45

TABLE XI

"This is the most generally useful stadia table for rods reading 1 foot to the 100 feet and with angles up to 30°. The values of other measures than those given in the table are obtained by multiplying the quantities under the proper vertical angle by stadia readings in hundreds of units. The quantity representing the focal distance is very small and is given at the bottom of each page for focal lengths between $\frac{3}{4}$ and $1\frac{1}{4}$ feet and is represented as a constant equal to c. For ordinary work it is not necessary to take the latter into account. The direct use of the table involves a multiplication for each result obtained.

"*Example.*—Let rod intercept be 3.25 feet, and the angle of inclination be 5° 35′. Then the distance on the horizontal would be

$$d=325 \text{ feet.}$$

"If we accept the focal distance $f+c$ as 1.25 feet, we have from the tables

$$d'=3.25 \text{ feet} \times 99.05+1.24=323.15 \text{ feet,}$$

and

$$h=3.25 \text{ feet} \times 9.68+0.11=31.57 \text{ feet.}$$

"The formulas by which the tables were computed are:

$$\text{Horizontal distance} = \cos^2 \text{ of vertical angle} \times 100.$$

"Difference of elevation $= \frac{1}{2}$ sin of twice the vertical angle × 100."

TABLE XI—*Continued*

HORIZONTAL DISTANCES AND ELEVATIONS FROM STADIA READINGS [1]

Minutes	0°		1°		2°		3°	
	Horizontal distance	Difference of elevation	Horizontal distance	Difference of elevation	Horizontal distance	Difference of elevation	Horizontal distance	Difference of elevation
0	100.00	0.00	99.97	1.74	99.88	3.49	99.73	5.23
2	100.00	0.06	99.97	1.80	99.87	3.55	99.72	5.28
4	100.00	0.12	99.97	1.86	99.87	3.60	99.71	5.34
6	100.00	0.17	99.96	1.92	99.87	3.66	99.71	5.40
8	100.00	0.23	99.96	1.98	99.86	3.72	99.70	5.46
10	100.00	0.29	99.96	2.04	99.86	3.78	99.69	5.52
12	100.00	0.35	99.96	2.09	99.85	3.84	99.69	5.57
14	100.00	0.41	99.95	2.15	99.85	3.90	99.68	5.63
16	100.00	0.47	99.95	2.21	99.84	3.95	99.68	5.69
18	100.00	0.52	99.95	2.27	99.84	4.01	99.67	5.75
20	100.00	0.58	99.95	2.33	99.83	4.07	99.66	5.80
22	100.00	0.64	99.94	2.38	99.83	4.13	99.66	5.86
24	100.00	0.70	99.94	2.44	99.82	4.18	99.65	5.92
26	99.99	0.76	99.94	2.50	99.82	4.24	99.64	5.98
28	99.99	0.81	99.93	2.56	99.81	4.30	99.63	6.04
30	99.99	0.87	99.93	2.62	99.81	4.36	99.63	6.09
32	99.99	0.93	99.93	2.67	99.80	4.42	99.62	6.15
34	99.99	0.99	99.93	2.73	99.80	4.48	99.62	6.21
36	99.99	1.05	99.92	2.79	99.79	4.53	99.61	6.27
38	99.99	1.11	99.92	2.85	99.79	4.59	99.60	6.33
40	99.99	1.16	99.92	2.91	99.78	4.65	99.59	6.38
42	99.99	1.22	99.91	2.97	99.78	4.71	99.59	6.44
44	99.98	1.28	99.91	3.02	99.77	4.76	99.58	6.50
46	99.98	1.34	99.90	3.08	99.77	4.82	99.57	6.56
48	99.98	1.40	99.90	3.14	99.76	4.88	99.56	6.61
50	99.98	1.45	99.90	3.20	99.76	4.94	99.55	6.67
52	99.98	1.51	99.89	3.26	99.75	4.99	99.55	6.73
54	99.98	1.57	99.89	3.31	99.74	5.05	99.54	6.78
56	99.97	1.63	99.89	3.37	99.74	5.11	99.53	6.84
58	99.97	1.69	99.88	3.43	99.73	5.17	99.52	6.90
60	99.97	1.74	99.88	3.49	99.73	5.23	99.51	6.96
$c = 0.75$	0.75	0.01	0.75	0.02	0.75	0.03	0.75	0.05
$c = 1.00$	1.00	0.01	1.00	0.03	1.00	0.04	1.00	0.06
$c = 1.25$	1.25	0.02	1.25	0.03	1.25	0.05	1.25	0.08

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[1] U. S. G. S. Bull. No. 650, Geographic Tables and Formulas, pages 353–359.

TABLE XI—*Continued*

HORIZONTAL DISTANCES AND ELEVATIONS FROM STADIA READINGS

Minutes	4°		5°		6°		7°	
	Horizontal distance	Difference of elevation	Horizontal distance	Difference of elevation	Horizontal distance	Difference of elevation	Horizontal distance	Difference of elevation
0	99.51	6.96	99.24	8.68	98.91	10.40	98.51	12.10
2	99.51	7.02	99.23	8.74	98.90	10.45	98.50	12.15
4	99.50	7.07	99.22	8.80	98.88	10.51	98.48	12.21
6	99.49	7.13	99.21	8.85	98.87	10.57	97.47	12.26
8	99.48	7.19	99.20	8.91	98.86	10.62	98.46	12.32
10	99.47	7.25	99.19	8.97	98.85	10.68	98.44	12.38
12	99.46	7.30	99.18	9.03	98.83	10.74	98.43	12.43
14	99.46	7.36	99.17	9.08	98.82	10.79	98.41	12.49
16	99.45	7.42	99.16	9.14	98.81	10.85	98.40	12.55
18	99.44	7.48	99.15	9.20	98.80	10.91	98.39	12.60
20	99.43	7.53	99.14	9.25	98.78	10.96	98.37	12.66
22	99.42	7.59	99.13	9.31	98.77	11.02	98.36	12.72
24	99.41	7.65	99.11	9.37	98.76	11.08	98.34	12.77
26	99.40	7.71	99.10	9.43	98.74	11.13	98.33	12.83
28	99.39	7.76	99.09	9.48	98.73	11.19	98.31	12.88
30	99.38	7.82	99.08	9.54	98.72	11.25	98.29	12.94
32	99.38	7.88	99.07	9.60	98.71	11.30	98.28	13.00
34	99.37	7.94	99.06	9.65	98.69	11.36	98.27	13.05
36	99.36	7.99	99.05	9.71	98.68	11.42	98.25	13.11
36	99.35	8.05	99.04	9.77	98.67	11.47	98.24	13.17
40	99.34	8.11	99.03	9.83	98.65	11.53	98.22	13.22
42	99.33	8.17	99.01	9.88	98.64	11.59	98.20	13.28
44	99.32	8.22	99.00	9.94	98.63	11.64	98.19	13.33
46	99.31	8.28	98.99	10.00	98.61	11.70	98.17	13.39
48	99.30	8.34	98.98	10.05	98.60	11.76	98.16	13.45
50	99.29	8.40	98.97	10.11	98.58	11.81	98.14	13.50
52	99.28	8.45	98.96	10.17	98.57	11.87	98.13	13.56
54	99.27	8.51	98.94	10.22	98.56	11.93	98.11	13.61
56	99.26	8.57	98.93	10.28	98.54	11.98	98.10	13.67
58	99.25	8.63	98.92	10.34	98.53	12.04	98.08	13.73
60	99.24	8.68	98.91	10.40	98.51	12.10	98.06	13.78
$c=0.75$	0.75	0.06	0.75	0.07	0.75	0.08	0.74	0.10
$c=1.00$	1.00	0.08	0.99	0.09	0.99	0.11	0.99	0.13
$c=1.25$	1.25	0.10	1.24	0.11	1.24	0.14	1.24	0.16

TABLE XI—*Continued*

HORIZONTAL DISTANCES AND ELEVATIONS FROM STADIA READINGS

Minutes	8°		9°		10°		11°	
	Horizontal distance	Difference of elevation	Horizontal distance	Difference of elevation	Horizontal distance	Difference of elevation	Horizontal distance	Difference of elevation
0	98.06	13.78	97.55	15.45	96.98	17.10	96.36	18.73
2	98.05	13.84	97.53	15.51	96.96	17.16	96.34	18.78
4	98.03	13.89	97.52	15.56	96.94	17.21	96.32	18.84
6	98.01	13.95	97.50	15.62	96.92	17.26	96.29	18.89
8	98.00	14.01	97.48	15.67	96.90	17.32	96.27	18.95
10	97.98	14.06	97.46	15.73	96.88	17.37	96.25	19.00
12	97.97	14.12	97.44	15.78	96.86	17.43	96.23	19.05
14	97.95	14.17	97.43	15.84	96.84	17.48	96.21	19.11
16	97.93	14.23	97.41	15.89	96.82	17.54	96.18	19.16
18	97.92	14.28	97.39	15.95	96.80	17.59	96.16	19.21
20	97.90	14.34	97.37	16.00	96.78	17.65	96.14	19.27
22	97.88	14.40	97.35	16.06	96.76	17.70	96.12	19.32
24	97.87	14.45	97.33	16.11	96.74	17.76	96.09	19.38
26	97.85	14.51	97.31	16.17	96.72	17.81	96.07	19.43
28	97.83	14.56	97.29	16.22	96.70	17.86	96.05	19.48
30	97.82	14.62	97.28	16.28	96.68	17.92	96.03	19.54
32	97.80	14.67	97.26	16.33	96.66	17.97	96.00	19.59
34	97.78	14.73	97.24	16.39	96.64	18.03	95.98	19.64
36	97.76	14.79	97.22	16.44	96.62	18.08	95.96	19.70
38	97.75	14.84	97.20	16.50	96.60	18.14	95.93	19.75
40	97.73	14.90	97.18	16.55	96.57	18.19	95.91	19.80
42	97.71	14.95	97.16	16.61	96.55	18.24	95.89	19.86
44	97.69	15.01	97.14	16.66	96.53	18.30	95.86	19.91
46	97.68	15.06	97.12	16.72	96.51	18.35	95.84	19.96
48	97.66	15.12	97.10	16.77	96.49	18.41	95.82	20.02
50	97.64	15.17	97.08	16.83	96.47	18.46	95.79	20.07
52	97.62	15.23	97.06	16.88	96.45	18.51	95.77	20.12
54	97.61	15.28	97.04	16.94	96.42	18.57	95.75	20.18
56	97.59	15.34	97.02	16.99	96.40	18.62	95.72	20.23
58	97.57	15.40	97.00	17.05	96.38	18.68	95.70	20.28
60	97.55	15.45	96.98	17.10	96.36	18.73	95.68	20.34
$c = 0.75$	0.74	0.11	0.74	0.12	0.74	0.14	0.73	0.15
$c = 1.00$	0.99	0.15	0.99	0.16	0.98	0.18	0.98	0.20
$c = 1.25$	1.23	0.18	1.23	0.21	1.23	0.23	1.22	0.25

TABLE XI—*Continued*

HORIZONTAL DISTANCES AND ELEVATIONS FROM STADIA READINGS

Minutes	12°		13°		14°		15°	
	Horizontal distance	Difference of elevation	Horizontal distance	Difference of elevation	Horizontal distance	Difference of elevation	Horizontal distance	Difference of elevation
0	95.68	20.34	94.94	21.92	94.15	23.47	93.30	25.00
2	95.65	20.39	94.91	21.97	94.12	23.52	93.27	25.05
4	95.63	20.44	94.89	22.02	94.09	23.58	93.24	25.10
6	95.61	20.50	94.86	22.08	94.07	23.63	93.21	25.15
8	95.58	20.55	94.84	22.13	94.04	23.68	93.18	25.20
10	95.56	20.60	94.81	22.18	94.01	23.73	93.16	25.25
12	95.53	20.66	94.79	22.23	93.98	23.78	93.13	25.30
14	95.51	20.71	94.76	22.28	93.95	23.83	83.10	25.35
16	95.49	20.76	94.73	22.34	93.93	23.88	93.07	25.40
18	95.46	20.81	94.71	22.39	93.90	23.93	93.04	25.45
20	95.44	20.87	94.68	22.44	93.87	23.99	93.01	25.50
22	95.41	20.92	94.66	22.49	93.84	24.04	92.98	25.55
24	95.39	20.97	94.63	22.54	93.81	24.09	92.95	25.60
26	95.36	21.03	94.60	22.60	93.79	24.14	92.92	25.65
28	95.34	21.08	94.58	22.65	93.76	24.19	92.89	25.70
30	95.32	21.13	94.55	22.70	93.73	24.24	92.86	25.75
32	95.29	21.18	94.52	22.75	93.70	24.29	92.83	25.80
34	95.27	21.24	94.50	22.80	93.67	24.34	92.80	25.85
36	95.24	21.29	94.47	22.85	93.65	24.39	92.77	25.90
38	95.22	21.34	94.44	22.91	93.62	24.44	92.74	25.95
40	95.19	21.39	94.42	22.96	93.59	23.49	92.71	26.00
42	95.17	21.45	94.39	23.01	93.56	24.55	92.68	26.05
44	95.14	21.50	94.36	23.06	93.53	24.60	92.65	26.10
46	95.12	21.55	94.34	23.11	93.50	24.65	92.62	26.15
48	95.09	21.60	94.31	23.16	93.47	24.70	92.59	26.20
50	95.07	21.66	94.28	23.22	93.45	24.75	92.56	26.25
52	95.04	21.71	94.26	23.27	93.42	24.80	92.53	26.30
54	95.02	21.76	94.23	23.32	93.39	23.85	92.49	26.35
56	94.99	21.81	94.20	23.37	93.36	24.90	92.46	26.40
58	94.97	21.87	94.17	23.42	93.33	24.95	92.43	26.45
60	94.94	21.92	94.15	23.47	93.30	25.00	92.40	26.50
$c = 0.75$	0.73	0.16	0.73	0.17	0.73	0.19	0.72	0.20
$c = 1.00$	0.98	0.22	0.97	0.23	0.97	0.25	0.96	0.27
$c = 1.25$	1.22	0.27	1.21	0.29	1.21	0.31	1.20	0.34

TABLE XI—*Continued*

HORIZONTAL DISTANCES AND ELEVATIONS FROM STADIA READINGS

Minutes	16°		17°		18°		19°	
	Horizontal distance	Difference of elevation	Horizontal distance	Difference of elevation	Horizontal distance	Difference of elevation	Horizontal distance	Difference of elevation
0	92.40	26.50	91.45	27.96	90.45	29.39	89.40	30.78
2	92.37	26.55	91.42	28.01	90.42	29.44	89.36	30.83
4	92.34	26.59	91.39	28.06	90.38	29.48	89.33	30.87
6	92.31	26.64	91.35	28.10	90.35	29.53	89.29	30.92
8	92.28	26.69	91.32	28.15	90.31	29.58	89.26	30.97
10	92.25	26.74	91.29	28.20	90.28	29.62	89.22	31.01
12	92.22	26.79	91.26	28.25	90.24	29.67	89.18	31.06
14	92.19	26.84	91.22	28.30	90.21	29.72	89.15	31.10
16	92.15	26.89	91.19	28.34	90.18	29.76	89.11	31.15
18	92.12	26.94	91.16	28.39	90.14	29.81	89.08	21.19
20	92.09	26.99	91.12	28.44	90.11	29.86	89.04	31.24
22	92.06	27.04	91.09	28.49	90.07	29.90	89.00	31.28
24	92.03	27.09	91.06	28.54	90.04	29.95	88.96	31.33
26	92.00	27.13	91.02	28.58	90.00	30.00	88.93	31.38
28	91.97	27.18	90.99	28.63	89.97	30.04	88.89	31.42
30	91.93	27.23	90.96	28.68	89.93	30.09	88.86	31.47
32	91.90	27.28	90.92	28.73	89.90	30.14	88.82	31.51
34	91.87	27.33	90.89	28.77	89.86	30.19	88.78	31.56
36	91.84	27.38	90.86	28.82	89.83	30.23	88.75	31.60
38	91.81	27.43	90.82	28.87	89.79	30.28	88.71	31.65
40	91.77	27.48	90.79	28.92	89.76	30.32	88.67	31.69
42	91.74	27.52	90.76	28.96	89.72	30.37	88.64	31.74
44	91.71	27.57	90.72	29.01	89.69	30.41	88.60	31.78
46	91.68	27.62	90.69	29.06	89.65	30.46	88.56	31.83
48	91.65	27.67	90.66	29.11	89.61	30.51	88.53	31.87
50	91.61	27.72	90.62	29.15	89.58	30.55	88.49	31.92
52	91.58	27.77	90.59	29.20	89.54	30.60	88.45	31.96
54	91.55	27.81	90.55	29.25	89.51	30.65	88.41	32.01
56	91.52	27.86	90.52	29.30	89.47	30.69	88.38	32.05
58	91.48	27.91	90.48	29.34	89.44	30.74	88.34	32.09
60	91.45	27.96	90.45	29.39	89.40	30.78	88.30	32.14
$c=0.75$	0.72	0.21	0.72	0.23	0.71	0.24	0.71	0.25
$c=1.00$	0.86	0.28	0.95	0.30	0.95	0.32	0.94	0.33
$c=1.25$	1.20	0.35	1.19	0.38	1.19	0.40	1.18	0.42

TABLE XI—*Continued*

HORIZONTAL DISTANCES AND ELEVATIONS FROM STADIA READINGS

Minutes	20°		21°		22°		23°	
	Horizontal distance	Difference of elevation	Horizontal distance	Difference of elevation	Horizontal distance	Difference of elevation	Horizontal distance	Difference of elevation
0	88.30	32.14	87.16	33.46	85.97	34.73	84.73	35.97
2	88.26	32.18	87.12	33.50	85.93	34.77	84.69	36.01
4	88.23	32.23	87.08	33.54	85.89	34.82	84.65	36.05
6	88.19	32.27	87.04	33.59	85.85	34.86	84.61	36.09
8	88.15	32.32	87.00	33.63	85.80	34.90	84.57	36.13
10	88.11	32.36	86.96	33.67	85.76	34.94	84.52	36.17
12	88.08	32.41	86.92	33.72	85.72	34.98	84.48	36.21
14	88.04	32.45	86.88	33.76	85.68	35.02	84.44	36.25
16	88.00	32.49	86.84	33.80	85.64	35.07	84.40	36.29
18	87.96	32.54	86.80	33.84	85.60	35.11	84.35	36.33
20	87.93	32.58	86.77	33.89	85.56	35.15	84.31	36.37
22	87.89	32.63	86.73	33.93	85.52	35.19	84.27	36.41
24	87.85	32.67	86.69	33.97	85.48	35.23	84.23	36.45
26	87.81	32.72	86.65	34.01	85.44	35.27	84.18	36.49
28	87.77	32.76	86.61	34.06	85.40	35.31	84.14	36.53
30	87.74	32.80	86.57	34.10	85.35	35.36	84.10	36.57
32	87.70	32.85	86.53	34.14	85.31	35.40	84.06	36.61
34	87.66	32.89	86.49	34.18	85.27	35.44	84.01	36.65
36	87.62	32.93	86.45	34.23	85.23	35.48	83.97	36.69
38	87.58	32.98	86.41	34.27	85.19	35.52	83.93	36.73
40	87.54	33.02	86.37	34.31	85.15	35.56	83.89	36.77
42	87.51	33.07	86.33	34.35	85.11	35.60	83.84	36.80
44	87.47	33.11	86.29	34.40	85.07	35.64	83.80	36.84
46	87.43	33.15	86.25	34.44	85.02	35.68	83.76	36.88
48	87.39	33.20	86.21	34.48	84.98	35.72	83.72	36.92
50	87.35	33.24	86.17	34.52	84.94	35.76	83.67	36.96
52	87.31	33.28	86.13	34.57	84.90	35.80	83.63	37.00
54	87.27	33.33	86.09	34.61	84.86	35.85	83.59	37.04
56	87.24	33.37	86.05	34.65	84.82	35.89	83.54	37.08
58	87.20	33.41	86.01	34.69	84.77	35.93	83.50	37.12
60	87.16	33.46	85.97	34.73	84.73	35.97	83.46	37.16
$c = 0.75$	0.70	0.26	0.70	0.27	0.69	0.29	0.69	0.30
$c = 1.00$	0.94	0.35	0.93	0.37	0.92	0.38	0.92	0.40
$c = 1.25$	1.17	0.44	1.16	0.46	1.15	0.48	1.15	0.50

TABLE XI—*Continued*

HORIZONTAL DISTANCES AND ELEVATIONS FROM STADIA READINGS

Minutes	24°		25°		26°		27°	
	Horizontal distance	Difference of elevation	Horizontal distance	Difference of elevation	Horizontal distance	Difference of elevation	Horizontal distance	Difference of elevation
0	83.46	37.16	82.14	38.30	80.78	39.40	79.39	40.45
2	83.41	37.20	82.09	38.34	80.74	39.44	79.34	40.49
4	83.37	37.23	82.05	38.38	80.69	39.47	79.30	40.52
6	83.33	37.27	82.01	38.41	80.65	39.51	79.25	40.55
8	83.28	37.31	81.96	38.45	80.60	39.54	79.20	40.59
10	83.24	37.35	81.92	38.49	80.55	39.58	79.15	40.62
12	83.20	37.39	81.87	38.53	80.51	39.61	79.11	40.66
14	83.15	37.43	81.83	38.56	80.46	39.65	79.06	40.69
16	83.11	37.47	81.78	38.60	80.41	39.69	79.01	40.72
18	83.07	37.51	81.74	38.64	80.37	39.72	87.96	40.76
20	83.02	37.54	81.69	38.67	80.32	39.76	78.92	40.79
22	82.98	37.58	81.65	38.71	80.28	39.79	78.87	40.82
24	82.93	37.62	81.60	38.75	80.23	39.83	78.82	40.86
26	82.89	37.66	81.56	38.78	80.18	39.86	78.77	40.89
28	82.85	37.70	81.51	38.82	80.14	39.90	78.73	40.92
30	82.80	37.74	81.47	38.86	80.09	39.93	78.68	40.96
32	82.76	37.77	81.42	38.89	80.04	39.97	78.63	40.99
34	82.72	37.81	81.38	38.93	80.00	40.00	78.58	41.02
36	82.67	37.85	81.33	38.97	79.95	40.04	78.54	41.06
38	82.63	37.89	81.28	39.00	79.90	40.07	78.49	41.09
40	82.58	37.93	81.24	39.04	79.86	40.11	78.44	41.12
42	82.54	37.96	81.19	39.08	79.81	40.14	78.39	41.16
44	82.49	38.00	81.15	39.11	79.76	40.18	78.34	41.19
46	82.45	38.04	81.10	39.15	79.72	40.21	78.30	41.22
48	82.41	38.08	81.06	39.18	79.67	40.24	78.25	41.26
50	82.36	38.11	81.01	39.22	79.62	40.28	78.20	41.29
52	82.32	38.15	80.97	39.26	79.58	40.31	78.15	41.32
54	82.27	38.19	80.92	39.29	79.53	40.35	78.10	41.35
56	82.23	38.23	80.87	39.33	79.48	40.38	78.06	41.39
58	82.18	38.26	80.83	39.36	79.44	40.42	78.01	41.42
60	82.14	38.30	70.78	39.40	79.39	40.45	77.96	41.45
$c=0.75$	0.68	0.31	0.68	0.32	0.67	0.33	0.66	0.35
$c=1.00$	0.91	0.41	0.90	0.43	0.89	0.45	0.89	0.46
$c=1.25$	1.14	0.52	1.13	0.54	1.12	0.56	1.11	0.58

TABLE XI—*Continued*

HORIZONTAL DISTANCES AND ELEVATIONS FROM STADIA READINGS

Minutes	28°		29°		30°	
	Horizontal distance	Difference of elevation	Horizontal distance	Difference of elevation	Horizontal distance	Difference of elevation
0	77.96	41.45	76.50	42.40	75.00	43.30
2	77.91	41.48	76.45	42.43	74.95	43.33
4	77.86	41.52	76.40	42.46	74.90	43.36
6	77.81	41.55	76.35	42.49	74.85	43.39
8	77.77	41.58	76.30	42.53	74.80	43.42
10	77.72	41.61	76.25	42.56	74.75	43.45
12	77.67	41.65	76.20	42.59	74.70	43.47
14	77.62	41.68	76.15	42.62	74.65	43.50
16	77.57	41.71	76.10	42.65	74.60	43.53
18	77.52	41.74	76.05	42.68	74.55	43.56
20	77.48	41.77	75.00	42.71	74.49	43.59
22	77.42	41.81	75.95	42.74	74.44	43.62
24	77.38	41.84	75.90	42.77	74.39	43.65
26	77.33	41.87	75.85	42.80	74.34	43.67
28	77.28	41.90	75.80	42.83	74.29	43.70
30	77.23	41.93	75.75	42.86	74.24	43.73
32	77.18	41.97	76.70	42.89	74.19	43.76
34	77.13	42.00	75.65	42.92	74.14	43.79
36	77.09	42.03	75.60	42.95	74.09	43.82
38	77.04	42.06	75.55	42.98	74.04	43.84
40	76.99	42.09	75.50	43.01	73.99	43.87
42	76.94	42.12	75.45	43.04	73.93	43.90
44	76.89	42.15	75.40	43.07	73.88	43.93
46	76.84	42.19	73.35	43.10	73.83	43.95
48	76.79	42.22	75.30	43.13	76.78	43.98
50	76.74	52.25	75.25	43.16	73.73	44.01
52	76.69	42.28	75.20	43.18	73.68	44.04
54	76.64	42.31	75.15	43.21	73.63	44.07
56	76.59	42.34	75.10	43.24	73.58	44.09
58	76.55	42.37	75.05	43.27	73.52	44.12
60	76.50	42.40	75.00	43.30	73.47	44.15
$c=0.75$	0.66	0.36	0.65	0.37	0.65	0.38
$c=1.00$	0.88	0.48	0.87	0.49	0.86	0.51
$c=1.25$	1.10	0.60	1.09	0.62	1.08	0.64

TABLE XII

NATURAL SINES AND COSINES

SINE 0–45°   COSINE 45–90°

S	0′	10′	20′	30′	40′	50′	60′		D
0°	0000	0029	0058	0087	0116	0145	0175	89°	29
1	0175	0204	0233	0262	0291	0320	0349	88	29
2	0349	0378	0407	0436	0465	0494	0523	87	29
3	0523	0552	0581	0610	0640	0669	0698	86	29
4	0698	0727	0756	0785	0814	0843	0872	85	29
5	0872	0901	0929	0958	0987	1016	1045	84	29
6	1045	1074	1103	1132	1161	1190	1219	83	29
7	1219	1248	1276	1305	1334	1363	1392	82	29
8	1392	1421	1449	1478	1507	1536	1564	81	29
9	1564	1593	1622	1650	1679	1708	1736	80	29
10	1736	1765	1794	1822	1851	1880	1908	79	29
11	1908	1937	1965	1994	2022	2051	2079	78	28
12	2079	2108	2136	2164	2193	2221	2250	77	28
13	2250	2278	2306	2334	2363	2391	2419	76	28
14	2419	2447	2476	2504	2532	2560	2588	75	28
15	2588	2616	2644	2672	2700	2728	2756	74	28
16	2756	2784	2812	2840	2868	2896	2924	73	28
17	2924	2952	2979	3007	3035	3062	3090	72	28
18	3090	3118	3145	3173	3201	3228	3256	71	28
19	3256	3283	3311	3338	3365	3393	3420	70	27
20	3420	3448	3475	3502	3529	3557	3584	69	27
21	3584	3611	3638	3665	3692	3719	3746	68	27
22	3746	3773	3800	3827	3854	3881	3907	67	27
23	3907	3934	3961	3987	4014	4041	4067	66	27
24	4067	4094	4120	4147	4173	4200	4226	65	26
25	4226	4253	4279	4305	4331	4358	4384	64	26
26	4384	4410	4436	4462	4488	4514	4540	63	26
27	4540	4566	4592	4617	4643	4669	4695	62	26
28	4695	4720	4746	4772	4797	4823	4848	61	25
29	4848	4874	4899	4924	4950	4975	5000	60	25
30	5000	5025	5050	5075	5100	5125	5150	59	25
31	5150	5175	5200	5225	5250	5275	5299	58	25
32	5299	5324	5348	5373	5398	5422	5446	57	24
33	5446	5471	5495	5519	5544	5568	5592	56	24
34	5592	5616	5640	5664	5688	5712	5736	55	24
35	5736	5760	5783	5807	5831	5854	5878	54	23
36	5878	5901	5925	5948	5972	5995	6018	53	23
37	6018	6041	6065	6088	6111	6134	6157	52	23
38	6157	6180	6202	6225	6248	6271	6293	51	23
39	6293	6316	6338	6361	6383	6406	6428	50	22
40	6428	6450	6472	6494	6517	6539	6561	49	22
41	6561	6583	6604	6626	6648	6670	6691	48	22
42	6691	6713	6734	6756	6777	6799	6820	47	21
43	6820	6841	6862	6884	6905	6926	6947	46	21
44	6947	6967	6988	7009	7030	7050	7071	45	21
	60′	50′	40′	30′	20′	10′	0′	C	D

TABLE XII—*Continued*

SINE **45–90°** COSINE **0–45°**

S	0′	10′	20′	30′	40′	50′	60′		D
45°	7071	7092	7112	7133	7153	7173	7193	44°	20
46	7193	7214	7234	7254	7274	7294	7314	43	20
47	7314	7333	7353	7373	7392	7412	7431	42	20
48	7431	7451	7470	7490	7509	7528	7547	41	19
49	7547	7566	7585	7604	7623	7642	7660	**40**	19
50	7660	7679	7698	7716	7735	7753	7771	39	18
51	7771	7790	7808	7826	7844	7862	7880	38	18
52	7880	7898	7916	7934	7951	7969	7986	37	18
53	7986	8004	8021	8039	8056	8073	8090	36	17
54	8090	8107	8124	8141	8158	8175	8192	**35**	17
55	8192	8208	8225	8241	8258	8274	8290	34	16
56	8290	8307	8323	8339	8355	8371	8387	33	16
57	8387	8403	8418	8434	8450	8465	8480	32	16
58	8480	8496	8511	8526	8542	8557	8572	31	15
59	8572	8587	8601	8616	8631	8646	8660	**30**	15
60	8660	8675	8689	8704	8718	8732	8746	29	14
61	8746	8760	8774	8788	8802	8816	8829	28	14
62	8829	8843	8857	8870	8884	8897	8910	27	13
63	8910	8923	8936	8949	8962	8975	8988	26	13
64	8988	9001	9013	9026	9038	9051	9063	**25**	12
65	9063	9075	9088	9100	9112	9124	9135	24	12
66	9135	9147	9159	9171	9182	9194	9205	23	12
67	9205	9216	9228	9239	9250	9261	9272	22	11
68	9272	9283	9293	9304	9315	9325	9336	21	11
69	9336	9346	9356	9367	9377	9387	9397	**20**	10
70	9397	9407	9417	9426	9436	9446	9455	19	10
71	9455	9465	9474	9483	9292	9502	9511	18	9
72	9511	9520	9528	9537	9546	9555	9563	17	9
73	9563	9572	9580	9588	9596	9605	9613	16	8
74	9613	9621	9628	9636	9644	9652	9659	**15**	8
75	9659	9667	9674	9681	9689	9696	9703	14	7
76	9703	9710	9717	9724	9730	9737	9744	13	7
77	9744	9750	9757	9763	9769	9775	9781	12	6
78	9781	9787	9793	9799	9805	9811	9816	11	6
79	9816	9822	9827	9833	9838	9843	9848	**10**	5
80	9848	9853	9858	9863	9868	9872	9877	9	5
81	9877	9881	9886	9890	9894	9899	9903	8	4
82	9903	9907	9911	9914	9918	9922	9925	7	4
83	9925	9929	9932	9936	9939	9942	9945	6	3
84	9945	9948	9951	9954	9957	9959	9962	**5**	3
85	9962	9964	9967	9969	9971	9974	9976	4	2
86	9976	9978	9980	9981	9983	9985	9986	3	2
87	9986	9988	9989	9990	9992	9993	9994	2	1
88	9994	9995	9996	9997	9997	9998	9998	1	1
89	9998	9999	9999	10000	10000	10000	10000	**0°**	0
	60′	**50′**	**40′**	**30′**	**20′**	**10′**	**0′**	C	D

TABLE XIII

LOGARITHMS 1 TO 100

N	0	1	2	3	4	5	6	7	8	9	D
10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374	42
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755	38
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106	35
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430	32
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732	30
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014	28
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279	26
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529	25
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765	24
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989	22
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	21
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	20
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	19
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	18
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	18
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	17
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	16
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	16
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	15
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	15
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	14
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	14
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	13
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	13
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	13
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	12
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	12
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	12
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	11
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	11
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	11
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	10
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	10
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	10
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	10
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	10
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	9
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	9
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	9
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	9
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	9
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	8
52	7160	7168	6177	7185	7193	7202	7210	7218	7226	7235	8
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	8
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	8

$\log_{10} e = .4343$

TABLE XIII—*Continued*

N	0	1	2	3	4	5	6	7	8	9	D
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	8
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	8
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	8
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	7
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	7
60	7782	7789	7796	7803	7810	7818	7825	8732	7839	7846	7
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	7
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	7
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	7
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	7
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	7
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	7
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	6
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	6
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	6
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	6
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	6
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	6
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	6
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	6
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	6
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	6
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	6
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	6
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	5
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	5
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	5
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	5
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	5
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	5
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	5
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	5
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	5
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	5
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	5
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	5
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	5
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	5
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	5
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	5
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	5
96	9823	9827	9832	9836	8941	9845	9850	9854	9859	9863	5
97	9868	9872	9877	9881	8986	9890	9894	9899	9903	9908	4
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	4
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996	4

$\log_{10} \pi = .49715$

TABLE XIV

Log sin and cos 0° to 90°

LOG SIN 0–45° LOG COS 45–90°

L S	0′	10′	20′	30′	40′	50′	60′		D
0°	....	7.4637	7.7648	7.9408	8.0658	8.1627	8.2419	89°	...
1	8.2419	8.3088	8.3668	8.4179	8.4637	8.5050	8.5428	88	...
2	8.5428	8.5776	8.6097	8.6397	8.6677	8.6940	8.7188	87	300
3	8.7188	8.7423	8.7645	8.7857	8.8059	8.8251	8.8436	86	210
4	8.8436	8.8613	8.8783	8.8946	8.9104	8.9256	8.9403	85	165
5	8.9403	8.9545	8.9682	8.9816	8.9945	*0070	*0192	84	132
6	*0192	0311	0426	0539	0648	0755	0859	83	112
7	0859	0961	1060	1157	1252	1345	1436	82	97
8	1436	1525	1612	1697	1781	1863	1943	81	85
9	1943	2022	2100	2176	2251	2324	2397	80	76
10	2397	2468	2538	2606	2674	2740	2806	79	68
11	2806	2870	2934	2997	3058	3119	3179	78	62
12	3179	3238	3296	3353	3410	3466	3521	77	57
13	3521	3575	3629	3682	3734	3786	3837	76	52
14	3837	3887	3937	3986	4035	4083	4130	75	49
15	4130	4177	4223	4269	4314	4359	4403	74	45
16	4403	4447	4491	4533	4576	4618	4659	73	43
17	4659	4700	4741	4781	4821	4861	4900	72	40
18	4900	4939	4977	5015	5052	5090	5126	71	38
19	5126	5163	5199	5235	5270	5306	5341	70	36
20	5341	5375	5409	5443	5477	5510	5543	69	34
21	5543	5576	5609	5641	5673	5704	5736	68	32
22	5736	5767	5798	5828	5859	5889	5919	67	30
23	5919	5948	5978	6007	6036	6065	6093	66	29
24	6093	6121	6149	6177	6205	6232	6259	65	28
25	6259	6286	6313	6340	6366	6392	6418	64	26
26	6418	6444	6470	6495	6521	6546	6570	63	25
27	6570	6595	6620	6644	6668	6692	6716	62	24
28	6716	6740	6763	6787	6810	6833	6856	61	23
29	6856	6878	6901	6923	6946	6968	6990	60	22
30	6990	7012	7033	7055	7076	7097	7118	59	21
31	7118	7139	7160	7181	7201	7222	7242	58	21
32	7242	7262	7282	7302	7322	7342	7361	57	20
33	7361	7380	7400	7419	7438	7457	7476	56	19
34	7476	7494	7513	7531	7550	7568	7586	55	18
35	7586	7604	7622	7640	7657	7675	7692	54	18
36	7692	7710	7727	7744	7761	7778	7795	53	17
37	7795	7811	7828	7844	7861	7877	7983	52	16
38	7893	7910	7926	7941	7957	7973	7989	51	16
39	7989	8004	8020	8035	8050	8066	8081	50	15
40	8081	8096	8111	8125	8140	8155	8169	49	15
41	8169	8184	8198	8213	8227	8241	8255	48	14
42	8255	8269	7283	8297	8311	8324	8338	47	14
43	8338	8351	8365	8378	8391	8405	8418	46	13
44	8418	8431	8444	8457	8469	8482	8495	45°	13
	60′	50′	40′	30′	20′	10′	0′	L C	D

* Char $=9-10$ *when not printed.*

TABLE XIV—*Continued*

LOG SIN 45–90° LOG COS 0–45°

L S	0′	10′	20′	30′	40′	50′	60′		D
45°	*8495	8507	8520	8532	8545	8557	8569	44°	12
46	8569	8582	8594	8606	8618	8629	9641	43	12
47	8641	8653	8665	8676	8688	8699	8711	42	12
48	8711	8722	8733	8745	8756	8767	8778	41	11
49	8778	8789	8800	8810	8821	8832	8843	40	11
50	8843	8853	8864	8874	8884	8895	8905	39	10
51	8905	8915	8925	8935	8945	8955	8965	38	10
52	8965	8975	8985	8995	9004	9014	9023	37	10
53	9023	9033	9042	9052	9061	9070	9080	36	9
54	9080	9089	9098	9107	9116	9125	9134	35	9
55	9134	9142	9151	9160	9169	9177	9186	34	9
56	9186	9194	9203	9211	9219	9228	9236	33	8
57	9236	9244	9252	9260	9268	9276	9284	32	8
58	9284	9292	9300	9308	9315	9323	9331	31	8
59	9331	9338	9346	9353	9361	9368	9375	30	7
60	9375	9383	9390	9397	9404	9411	9418	29	7
61	9418	9425	9432	9439	9446	9453	9459	28	7
62	9459	9466	9473	9479	9486	9492	9499	27	7
63	9499	9505	9512	9518	9524	9530	9537	26	6
64	9537	9543	9549	9555	9561	9567	9573	25	6
65	9573	9579	9584	9590	9596	9602	9607	24	6
66	9607	9613	9618	9624	9629	9635	9640	23	6
67	9640	9646	9651	9656	9661	9667	9672	22	5
68	9672	9677	9682	9687	9692	9697	9702	21	5
69	9702	9706	9711	9716	9721	9725	9730	20	5
70	9730	9734	9739	9743	9748	9752	9757	19	4
71	9757	9761	9765	9770	9774	9778	9782	18	4
72	9782	9786	9790	9794	9798	9802	9806	17	4
73	9806	9810	9814	9817	9821	9825	9828	16	4
74	9828	9832	9836	9839	9843	9846	9849	15	3
75	9849	9853	9856	9859	9963	9866	9869	14	3
76	9869	9872	9875	9878	9881	9884	9887	13	3
77	9887	9890	9893	9896	9899	9901	9904	12	3
78	9904	9907	9909	9912	9914	9917	9919	11	3
79	9919	9922	9924	9927	9929	9931	9934	10	2
80	9934	9936	9938	9940	9942	9944	9946	9	2
81	9946	9948	9950	9952	9954	9956	9958	8	2
82	9958	9959	9961	9963	9964	9966	9968	7	2
83	9968	9969	9971	9972	9973	9975	9976	6	1
84	9976	9977	9979	9980	9981	9982	9983	5	1
85	9983	9985	9986	9987	9988	9989	9989	4	1
86	9989	9990	9991	9992	9993	9993	9994	3	1
87	9994	9995	9995	9996	9996	9997	9997	2	0
88	9997	9998	9998	9999	9999	9999	*9999	1	0
89	9999	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0°	0
	60′	50′	40′	30′	40′	10′	0′	L C	D

* Char =9−10 *when not printed.*

TABLE XV

APPROXIMATE WELL DEPTHS FROM DRILLING CABLE

The following table is designed to enable the geologist to compute the depth of a well from the amount of cable that is wound up on the bull wheel when the tools are withdrawn.

If, for example, there are 3 complete coils, or layers, of 27 wraps each, and 4 wraps on the fourth coil counted on the bull wheel in bringing the bit from the bottom of the hole to the derrick floor, then the depth of the hole is 375.4 feet deep if the drilling cable is ¾-inch wire line. This depth is found as follows:

In the first coil on the bull wheel each wrap is 3.99 feet, the first wrap in the second coil is 4.38 feet, 4.77 feet in the third coil, and 5.16 in the fourth. Therefore,

$$\begin{array}{r} 27\times 3.99 = 107.73 \\ 27\times 4.38 = 118.26 \\ 27\times 4.77 = 128.79 \\ 4\times 5.16 = 20.64 \\ \hline 375.42 \text{ feet} \end{array}$$

If there are already some wraps or coils on the bull wheel these should be omitted in the computations. Thus if there are 5 wraps in the first coil on the wheel when the tools leave the bottom of the hole, then 19.95 feet must be taken from the total amount of cable in the first coil, 107.73 feet.

TABLES FOR APPROXIMATE WELL DEPTH. BULL WHEEL 14½" DIAMETER

2¼" MANILA ROPE.—NO. OF COILS

Wraps	1	2	3	4	5	6	7	8	9	10	11	12	13	Wraps
1	4.38	5.56	6.74	7.92	9.10	10.28	11.46	12.64	13.82	15.00	16.18	17.36	18.54	1
2	8.76	11.12	13.48	15.84	18.20	20.56	22.92	25.28	27.64	30.00	32.36	34.72	37.08	2
3	13.14	16.68	20.22	23.76	27.30	30.84	34.38	37.92	41.46	45.00	48.54	52.08	55.62	3
4	17.52	22.24	26.96	31.68	36.40	41.12	45.84	50.56	55.28	60.00	64.72	69.44	74.16	4
5	21.90	27.80	33.70	36.90	45.50	51.40	57.30	63.20	69.10	75.00	80.90	86.80	92.70	5
6	26.28	33.36	40.44	47.52	54.60	61.68	68.76	75.84	82.92	90.00	97.08	104.16	111.24	6
7	30.66	38.92	47.18	55.44	63.70	72.16	80.22	88.48	96.74	105.00	113.26	121.52	129.78	7
8	35.04	44.48	53.92	63.36	72.80	82.44	91.68	101.12	110.56	120.00	129.44	138.88	147.32	8
9	39.42	50.04	60.66	71.28	81.90	92.52	103.14	113.76	124.38	135.00	145.62	156.24	166.86	9
10	43.80	55.60	67.40	79.20	91.00	102.80	114.60	126.40	138.20	150.00	161.80	173.60	185.40	10

TABLES FOR APPROXIMATE WELL DEPTH. BULL WHEEL 14½" DIAMETER—*Continued*

¾" WIRE LINE. NO. OF COILS

Wraps	1	2	3	4	5	6	7	8	9	10	11	12	13	Wraps
1	3.99	4.38	4.77	5.16	5.55	5.94	6.33	6.72	7.11	7.50	7.89	8.28	8.67	1
2	7.98	8.76	9.54	10.32	11.10	11.88	12.66	13.44	14.22	15.00	15.78	16.56	17.34	2
3	11.97	13.14	14.31	15.48	16.65	17.82	18.99	20.16	21.33	22.50	23.67	24.84	26.01	3
4	15.96	17.52	19.08	20.64	22.20	23.76	25.32	26.88	28.44	30.00	31.56	33.12	34.68	4
5	19.95	21.90	23.85	25.80	27.75	29.70	31.65	33.60	35.55	37.50	39.45	41.40	43.35	5
6	23.94	26.28	28.62	30.96	33.30	35.64	37.98	40.32	42.66	45.00	47.34	49.68	52.02	6
7	27.93	30.66	33.39	36.12	38.85	41.58	44.31	47.04	49.77	52.50	55.23	57.96	60.69	7
8	31.92	35.04	38.16	41.28	44.40	47.52	50.64	53.76	56.88	60.00	63.12	66.24	69.36	8
9	35.91	39.42	42.93	46.44	49.95	53.46	56.97	60.48	63.99	67.50	71.01	74.52	78.03	9
10	39.90	43.80	47.70	51.60	55.50	59.40	63.30	67.20	71.10	75.00	78.90	82.80	86.70	10

TABLES FOR APPROXIMATE WELL DEPTH. BULL WHEEL 14½" DIAMETER—*Continued*

⅞" WIRE LINE. NO. OF COILS

Wraps	1	2	3	4	5	6	7	8	9	10	11	12	13	Wraps
1	4.02	4.48	4.94	5.40	5.86	6.32	6.78	7.24	7.70	8.16	8.62	9.08	9.54	1
2	8.04	8.96	9.88	10.80	11.72	12.64	13.56	14.48	15.40	16.32	17.24	18.16	19.08	2
3	12.06	13.44	14.82	16.20	17.58	18.96	20.34	21.72	23.10	24.48	25.86	27.24	28.62	3
4	16.08	17.92	19.76	21.60	23.44	25.28	27.12	28.96	30.80	32.64	34.48	36.32	38.16	4
5	20.10	22.40	24.70	27.00	29.30	31.60	33.90	36.20	38.50	40.80	43.10	45.40	47.70	5
6	24.12	26.88	29.64	32.40	35.16	37.92	40.68	43.44	46.20	48.96	51.72	54.48	57.24	6
7	28.14	31.36	34.58	39.80	41.02	44.24	47.46	50.68	53.90	57.12	60.34	63.56	66.78	7
8	32.16	35.84	39.52	43.20	46.88	50.56	54.24	57.92	61.60	65.28	68.96	72.64	76.32	8
9	36.18	40.32	44.46	48.60	52.74	56.88	61.02	65.16	69.30	73.44	77.48	81.72	85.86	9
10	40.20	44.80	49.40	54.00	58.60	63.20	67.80	72.40	77.00	81.60	86.20	90.80	95.40	10

GEOLOGIC CHRONOLOGY FOR NORTH AMERICA

Era	System	Series
Psychozoic		Recent and present
Cenozoic	Quaternary	Pleistocene
	Tertiary	Pliocene
		Miocene
		Oligocene
		Eocene
Mesozoic		Cretaceous
		Comanchian
		Jurassic
		Triassic
Paleozoic	Carboniferous	Permian
		Pennsylvanian
		Mississippian
		Devonian
		Silurian
		Ordovician
		Cambrian
Proterozoic	Algonkian	Great unconformity
		Keweenawan
		Animaikian
		Huronian
Archeozoic		

GENERAL GEOLOGIC SECTION FOR SOUTHERN OKLAHOMA

AFTER OKLAHOMA GEOLOGICAL SURVEY

System	Formation	Thickness, Ft.	Lithology
Comanche	Silo sandstone	250	Brown sandstone and shale; Unconformity
	Bennington limestone	25	Hard resistant formation forming low bluffs or benches
	Bochito form	130–150	Clays, sands, and siliceous limestones
	Caddo form	55–70	Interstratified clays, marls, and limes
	Kaimichi form	150+	Thin limestones and friable clays
	Goodland limestone	30+	Thin very hard limestone, forms tableland with steep escarpment at surface
	Trinity sand	400+	Loosely consolidated, friable sandstone, or compact sand, usually white or pink. Unconformity
	Permian	1500–2650	Gray and red sandstones and shales, gypsum and dolomite Unconformity
Pennsylvanian	Wapunacka limestone	300+	Massive limestone, chert, sandstone, and shale
	Franks conglomerate	0–200	Beds of chert gravel and sandstone, not extensive. Unconformity
	Glenn form	1000–3000	Blue clay shales and thin sandstones. Unconformity
Mississippian	Caney shale	1600+	Blue or black shale with fossiliferous limestone concretions
	Sycamore limestone	0–200	Light bluish to yellow or buff, with frequent joint planes
Devonian	Woodford chert	650+	Cherty layers, shale and small concretions
Silurian	Hunton form	300+	Limestones and shales
	Sylvan shale	60–300	Black to greenish shale
Ordovician	Viola limestone	500–700	Crystalline to dense, buff to bluish in color, contains chert nodules
	Simpson form	1200–2000	Massive, pure sandstones, shales and siliceous limestones
Cambro-Ordovician	Arbuckle limestone	3000–6000	White to light blue, many layers of thin dark-colored shale near the base. Regan contact—fine white quartz conglomerate
Cambrian	Regan sandstone	50–500	Arkosic and granitic at base, coarse quartz sandstone, green and red sands and shales
Pre-Cambrian	Tishomingo granite		Coarse and fine-grained pinkish gray biotite

GENERAL GEOLOGIC SECTION FOR NORTHERN OKLAHOMA

After Oklahoma Geological Survey

System	Formation	Thickness	Lithology
Permian	Red beds	1500–2650	Red and gray sandstones and shales, dolomites, limestones, gypsum and salt
Pennsylvanian	Undescribed	700	Alternating shales, sandstones and thin bedded limestones
	Elgin sandstone	50–140	Massive sandstone
	Oread	0–17	Breaks out into large slabs
	Buxton formation	450–600	Shales, sandstones and limestone
	Wilson formation	280–400	Sandstones, shales and limestones
	Dewey limestone	23	Bluish semi-crystalline, often massive
	Unnamed	75	Shales and sandstones
	Hogshooter limestone	10	Usually a single bed with very abundant fossils
	Coffeyville formation	370 +	Mostly shale, sandstone near top
	Lenapah limestone	3–20	Blue semi-crystalline limestone with fossils. No chert
	Nowata shales	50–130	Bluish to greenish clay shales
	Altamont limestone	25–35	Highly siliceous, hard, massive limestone
	Bandera shales	0–120	Bluish black shales
	Pawnee limestone	43 +	Massive and fine-grained limestone. Joins with Altamont to form Big Lime
	Labette shale	120–200	Thick shales with occasional heavy sandstones. Fine-grained buff sandstone found near top
	Ft. Scott formation	30–60	Two limestones with shale parting
	Cherokee formation	450–1500	A series of shales, sandstones, limestones and coal beds.
			Unconformity
Mississippian	Morrow formation	80–150	Limestone, shale, and local sandstone
	Pitkin limestone	50 +	Light blue to brown granular, earth, strata, interbedded with fine textured massive layers
	Fayetteville formation	20–170	Sandstones, shales, and limestones
	Boone formation	150–225	Interstratified chert and cherty limestone

GENERAL GEOLOGIC SECTION FOR THE OIL FIELDS OF KANSAS

AFTER STATE GEOLOGICAL SURVEY OF KANSAS, BULL. NO. 3

System	Formation	Thickness, Ft.	Lithology
Permian		1000–1500	Red and gray sandstone, some salt and gypsum in upper portion
	Wellington formation	75–150	Blue gray and slate-colored shale and important salt beds
	Marion formation	150±	Buff, thin-bedded limestones and shales
	Winfield formation	20–30	Limestone and shale; cherty limestone at base separated from upper concretionary one by yellowish shale
	Doyle shale	60±	Varicolored shale, containing thin slabs of limestone; forms gentle topography
	Ft. Riley	40–47	Basal part shaley, above which are thick cellular limestones. Upper part thin beds and at times oolotic
	Florence flint	19–23	Thin limestones with interbedded chert. At times contains white cellular sandstone
	Matfield shale	60–70	Varicolored; occasionally cherty limestone
	Wreford limestone	35–55	Two cherty members separated by heavy non-cherty limestone. Weathers reddish brown
	Garrison formation	140–150	Green, chocolate, and yellow shales, grayish limestone, and some gypsum
	Cottonwood limestone	6–10	Massive light gray foramiferal limestone. Contains some fusilina
	Eskridge shale	30–40	Massive greenish, chocolate, and yellowish-clay shales
	Neva limestone	10±	Breaks in large blocks with sharp angles and rough surfaces
	Elmdale formation	120–140	Alternating shale and grayish lime, abundant fusilina about 30 feet above base
Pennsylvanian	Americus limestone	6–8	Good building stone
	Admire formation	250–300	Many thin limestones, few sandstones, two or more thin seams of coal
	Emporia limestone	8–10	Interstratified blue limestone and shales
	Willard shale	60–190	Mainly clay shales

GENERAL GEOLOGIC SECTION FOR THE OIL FIELDS OF KANSAS—*Continued*

System	Formation	Thickness, Ft.	Lithology
Pennsylvanian	Burlingame limestone	6–12	Massive limestone, contains thin shales in southern part of the State
	Scranton shale	160–180	Carries a thin vein of coal about half way up the formation
	Howard limestone	2–7	Sometimes two members separated by a shale parting
	Severy shale	40–60	Contain a seam of coal 8 to 20 inches thick
	Topeka limestone	20–25	Cherty limestone with shale partings, considerable calcite. *Spifer cameratus*
	Calhoun shale	0–50	
	Deer Creek limestone	20–30	Bluish lime much fissured and broken
	Tecumseh shale	40–70	Blue arenaceous shales and uneven limestone
	Lecompton limestone	15–30	Interbedded gray limestone and clay shales. Contains many fusilina
	Kanawka shale	50–100	Clay shales, few thin seams of coal; lenses of argillaceous limestone
	Oread limestone	10–25	Compact, fine-grained, buff limestone; greenish blue when freshly broken; chert nodules
	Lawrence shale	200–300	Arenaceous shales and heavy beds of sandstone, ripple marked. Some coal and limestone
	Iatan limestone	5–15	Commonly forms great blocks on the face of hill
	Weston shale	60–100	Carry a small amount of coal
	Stanton limestone	20–40	Well-bedded limestone with shale partings; sometimes bituminous
	Villas shale	5–125	
	Plattsburg limestone	6–75	Highly crystalline; readily breaks into small fragments
	Lane shale	30–150	Irregularly deposited; little sandstone
	Iola limestone	2–44	Very crystalline and massive
	Chanute shale	25–100	Fine clay shale, often changing rapidly to sandstone and back to shale. In places thin seams of coal
	Drum limestone	5–80	Very pure limestone for cement; sometimes mixed with clay

GENERAL GEOLOGIC SECTION FOR THE OIL FIELDS OF KANSAS—*Continued*

System	Formation	Thickness Ft.	Lithology
Pennsylvanian	Cherryvale shale	40–125	High-grade clay shales to arenaceous shales
	Winterset (Dennis) limestone	5–25	White limestone with cherty masses near the top
	Galesburg shale	5–60	Arenaceous clay shale
	Bethany Falls limestone	3–16	Very pure massive white limestone. Weathers uneven
	Ladore shale	7–40	Clay shales
	Hertha limestone	15–25	Massive, very pure white limestone
	Pleasanton shale	125–150	Contains calcareous lentils and sandstone lenses. Oil at Paola and Rantoul
	Coffeyville limestone	2–50	Gray limestone with some shale partings
	Walnut shale	20–140	Gray clay shale
	Altamont limestone	3–10	Massive gray limestone
	Bandera shale	60–100	Shale, some coal, and good paving stone
	Pawnee limestone	10–60	Heavy white limestone, weathering out in boulders
	Labette shale	20–60	Blue clay shale, containing coal, and some limestone near the top
	Ft. Scott limestone	20–50	Light gray color, weathering buff; contains large crinoid remains
	Cherokee shale	400–500	Light gray to black shales, sandstones, coal, and some lime
Mississippian		320	Limestone, calcareous shale and chert

GENERAL SECTION OF ROCKS, OUTCROPPING IN GREEN RIVER FIELD, UTAH

U. S. G. S. Bull. No. 541

System	Formation	Member	Thickness (feet	Description of strata
Cretaceous	Mancos shale		about 2500 [1]	Yellow to bluish-drab sandy shale; the upper part is very sandy and contains beds and lenses of sandstone; the middle and lower parts are mainly shale
		Ferron sandstone member	50–100	This sandstone contains in places concretions which are fossiliferous. It forms a hogback through the field
			about 400	Bluish-drab sandy shale; sandy material is most plentiful near the base and top part of this formation
	Dakota sandstone		0–40	Yellowish-gray sandstone with thin beds of shale alternating. Sandstone, coarse, soft, and in places very conglomeratic.
				Unconformity
Jurassic (?)	McElmo formation		325–350	Gray conglomerate, variegated sandy shale, and clay and a few feet of limestone about 175 feet from the top. Some of the sandstone is quartzitic
		Salt Wash sandstone member	150–175	Gray conglomeratic sandstone which outcrops in cliffs. This sandstone in places is lenticular, soft, and friable
			about 700	Red sandstone, thin bedded above and massive below
Jurassic	La Plata formation		estimated 700	Very cross bedded coarse gray sandstone

[1] After Richardson.

PARTIAL GEOLOGIC SECTION EXPOSED IN THE COSTAL PLAIN OF TEXAS WEST OF THE BRAZOS RIVER [1]

THE BRENHAM SALT DOME, WASHINGTON AND AUSTIN COUNTIES, TEXAS, BY OLIVER B. HOPKINS. U. S. G. S. BULL. No. 661G

System	Series	Formation		Thickness (feet)	Lithology
Tertiary	Pliocene	Lagarto clay		200–400	Clay with lime concretions and calcareous cross-bedded sand. Clay, light-colored or green when fresh, black on weathering
		Lapara sand [2]		50–100	Sand and clay, interbedded; clay, red, green, and pink
	Miocene	Oakville sansdtone		200–300	Sandstone, gray, soft, calcareous in places; some clay lenses
	Oligocene	Catahoula sandstone		200	Sandstone, hard, blue, quartzitic; green, blue brown, and white clay; and gray cross-bedded sandstone
	Eocene	Frio clay		500	Clay, green and pink, with small lime nodules; beds of volcanic ash; beds of brown marl in lower part
		Fayette sandstone		800	Sandstone and sand, gray; brown and lignitic clay; volcanic ash and white kaolin-like clay
		Claiborne group.	Yegua form	600–720	Clay, dark green and brown, lignitic; sand, yellow, and dark colored; lignite
			Cook Mt. form	700–800	Green sand, green sand marl, iron ore, lignite, lignitic clay, clay, sandstone and sand. Glauconitic sand and clay predominating
			Mt. Selman form	600–700	Sand, dark green and brown; thin seams of iron ore; lenses of lignite and clay; beds generally iron bearing
			Carrizo sandstone	200–450	Sandstone, cross-grained, cross-bedded, calcareous in part; coarse quartzitic sand and fine-grained micaceous sandstone
			Wilcox form	350–650	Sand lenses, sandstone, clay, sandy clay, and lignite
		Midway formation		260	Clay and limestone of marine origin

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[1] From manuscript report by Alexander Deusen on Geology of Costal Plains of Texas west of Brazos River.

[2] This formation absent in the area near the Brenham dome.

PARTIAL GEOLOGIC SECTION EXPOSED IN THE COSTAL PLAIN OF TEXAS WEST OF THE BRAZOS RIVER.—*Continued*

System	Series	Formation	Thickness (feet)	Lithology
Cretaceous	Gulf (Upper Cretaceous)	Navarro formation	500–600	Marl, bluish-black, and glauconitic clay; blue clay with siderite and limonite concretions; yellow and brown sand with hard sandy concretions
		Taylor marl	600–700	Clay marl, blue, calcareous. West of Bexar County the Taylor marl is replaced by the Anacacho limestone
		Austin chalk	304–500	Chalk, interstratified with thin beds of soft marl
		Eagle Ford shale	21–200	Shale and thin arenaceous beds of laminated limestone

SECTION OF FORMATIONS IN VICKSBURG-JACKSON AREA, MISS.

STRUCTURE OF THE VICKSBURG-JACKSON AREA, MISS., WITH SPECIAL REFERENCE TO OIL AND GAS, BY O. B. HOPKINS.
U. S. G. S. BULL. No. 641D

System	Series	Group	Thickness (feet)	Character
Quaternary	Recent	Alluvium		Sand, clay, and silt along present streams
	Pleistocene	Loess and loam	0–100	Clay, fine, gray to buff, calcareous, and yellow to brown loam
		Alluvial terrace deposits	0–50	Sand, gravel, and clay
Tertiary	Pliocene	Sand and gravel	0–50	Terrace sand and gravel
	Oligocene	Catahoula sandstone	0–75	Unconsolidated sands, sandstones, gray siliceous clays, and some lignitic material
		Vicksburg limestone	80–130	Marl and clay above, containing marine shells; limestone, and impure limestone and marl below
	Eocene	Jackson formation	250–500	Sand above, cross-bedded, green to yellow non-fossiliferous gray clay, weathering black below, and sand beds at base. Both clay and sand beds contain marine shells
		Claiborne group	500–1000	Marls, sands, lignitic clays, and lignite above; quartzite, clay stone and marl below
		Wilcox group	850–1500(?)	Lignitic clays and sands, with sand predominating in middle part
Cretaceous	Upper	Midway	100–300	Clay, dark gray to black, and micaceous sandstone, with hard limestone and sandy marl below
		Ripley form	50–300	Sands, clays, marls, and impure limestones of marine origin
		Selma chalk	600–1000	Chalky limestone with argillaceous and sandy beds
		Eutaw form	300–400	Sands, massive and cross bedded
		Tuscaloosa formation	100–300	Irregularly bedded sands, clays, and gravels containing clay and lignite layers at the top

ROCK FORMATIONS IN THE SALT CREEK OIL FIELD, WYOMING

The Lander and Salt Creek Oil Fields, Wyoming, by E. G. Woodruff and C. H. Wegemann.
U. S. G. S. Bull. No. 452

System	Series	Group	Formations and number recognised in this field		Character	Thickness in feet
Tertiary	Eocene		Fort Union formation		Fine grained fresh-water sandstone, shale, and coal beds	Several thousand feet
Tertiary or Cretaceous	?		Lance formation		Concretionary buff sandstone and shale-bearing Triceratops remains. Fresh water	3200
		Montana	Fox Hills sandstone		White sandstone and shale. Marine	700?
			Pierre formation		Shale with several sandstone beds, including that which forms Little Pine Ridge. Marine	1000
				Parkman sandstone member	Massive buff sandstone overlain by shale and thin coal beds. Marine and fresh water	350
					Shale with sandstone stratum 250 feet above its base. Marine	1100
				Shannon sandstone lentil	Oil-bearing horizon near base. Marine	175
					Gray shale. Marine	1025

Cretaceous	Upper Cretaceous	Colorado	Niobrara shale		Light-colored shale in parts, somewhat arenaceous. Marine	735
			Benton shale		Dark shale, several calcareous beds. Marine	220
				Wall Creek sandstone lentil	Buff sandstone, ripple marked, and cross bedded. Petrified wood, marine shells and fish teeth. The principal oil sand of Salt Creek	80
					Dark shale, several sandstone beds. Marine	800
				Mowry shale member	Firm slaty shale, usually forming escarpment. Weathers light gray and bears numerous fish scales. Marine	300
					Dark shale with one thin persistent, strongly ripple-marked sandstone	270
			Dakota (?) sandstone		Conglomeratic sandstone, oil bearing. Fresh water	56
Jurassic?			Morrison formation		Variegated shale with several sandstone beds which in certain localities bear oil. Fresh water	250

GEOLOGIC FORMATIONS EXPOSED NEAR THERMOPOLIS, WYOMING

OIL IN THE WARM SPRINGS AND HAMILTON DOMES, NEAR THERMOPOLIS, WYOMING, BY A. J. COLLIER.

U. S. G. S. BULL. No. 711D

System	Formation or group	Thickness (feet)	Character of the rocks
Cretaceous	Frontier formation	390	Seven or more beds of gray and buff sandstones with interbedded gray and brown shales and bentonite. Marine deposits
	Mowry shale	266	Hard gray shale containing fish scales and having a few interbedded lenses of sandstone. A marine deposit
	Thermopolis shale	589	Gray to black shale with one persistent sandstone, called the Muddy sand by drillers, near its base. A marine deposit
	Cloverly formation	248	Two beds of massive buff sandstone separated by variegated shale. Upper bed is known as the Graybull sand. In part at least a fresh-water deposit
Cretaceous(?)	Morrison formation	145	Purplish and pale greenish-gray shales with sandstone interbedded. A fresh-water deposit
Jurassic	Sundance formation	240	Greenish-gray sandstone, shale, and limestone containing many oyster, *Gryphæa*, and belemnite shells. Marine deposits
Triassic	Chugwater formation	1200	"Red Beds." Red sandstone and shale containing beds of gypsum, the largest having a thickness of more than 60 feet near the top of the formation, and at least one bed of limestone near the middle. Largely fresh-water formation

GEOLOGIC FORMATIONS EXPOSED NEAR THERMOPOLIS, WYOMING—*Continued*

System	Formation or group	Thickness (feet)	Character of the rocks
Carboniferous	**Embar group**	270	About 60 feet of the upper part consists of calcareous shale, sandstone, and gypsum, which are not distinguished from the "Red Beds" by the drillers but which represent the Triassic Dinwoody formation.[1] Below this about 60 feet of limestone and about 150 feet of thin-bedded sandstone, reddish shale, and limestone, including the "Embar sand" of the drillers, represent the Park City formation.[1] The Embar is for the most part a marine deposit
	Tensleep sandstone	250	Gray cross-bedded sandstone. Probably marine
	Amsden formation	300	Red sandy shale and sandstone with layers of limestone and chert. Marine
	Madison limestone	600–1000	Gray massive limestone. Marine
Ordovician	Bighorn dolomite	150–300	Siliceous gray limestone. Marine
Cambrian	Deadwood formation	700–900	Sandstone, shale, conglomerate, and limestone. Marine
Pre-Cambrian	Metamorphic complex		A complex of schists, gneiss, etc.

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[1] Condit, D. D., Relations of the Embar and Chugwater formations in central Wyoming: U. S. Geol. Survey Prof. Paper 98, pp. 263–270, 1916.

ROCK FORMATIONS EXPOSED IN THE HUNTLEY FIELD, MONT.

GEOLOGY AND OIL AND GAS PROSPECTS OF THE HUNTLEY FIELD, MONTANA, BY E. T. HANCOCK.

U. S. G. S. BULL. No. 711G

Era	System	Series	Group and formation	Character	Topographic expression	Thickness (feet)
Cenozoic	Tertiary	Eocene	Fort Union formation	Yellowish to buff sandstone and sandy shale Lebo shale member. Dark olive-green to brown sandy shale and thin-bedded arkosic sandstone; contains a thick bed of carbonaceous shale, including thin layers of coal near the middle	Forms broad, more or less gentle slope extending back from the Lance formation to the massive sandstones forming the upper part of the Fort Union formation	100± 200–300
(?)	Tertiary(?)	Eocene (?)	Lance formation	Light yellowish-gray sandstone; gray, yellow, and drab clays and shales; and grayish sandy shale. The upper part contains some thin streaks of coal	Basal beds of the Lance formation commonly form a prominent escarpment along the margin of the depressed area underlain by the Bearpaw shale. Higher sandstones form scarps along the low ridges	700–1500
			Bearpaw shale	Dark marine shale containing numerous calcareous concretions. Abundantly fossiliferous	In many places weathers down to broad valleys and shallow basins between the more resistant sandstones of the Judith River and Lance formations. Also forms the sides of elevated ridges where protected by a cap of gravel and conglomerate	Undetermined; 500 to 600 feet in the adjoining Lake Basin field

Mesozoic	Cretaceous	Upper Cretaceous	Montana group.	Judith River formation	Light-yellow soft massive sandstones containing considerable dark carbonaceous material and dark shale. At the base is a brown, irregularly jointed and hackly sandstone, alternating with zones of greenish-gray sandy shale, which seems to be the approximate equivalent of the sandstone included in the upper part of the Claggett formation in its type area; but for convenience of mapping and because of lithologic similarity this sandstone is here included in the Judith River formation	If dipping rather steeply the beds form rather prominent ridges between the valleys eroded out of the Bearpaw above and the Claggett below. Where nearly flat lying the hard basal sandstones form rather prominent escarpments around the broad valleys eroded out of the Claggett formation	100–500
				Claggett formation	Dark-gray marine shale, including zones of thin-bedded sandstone which locally become very massive and form prominent cliffs. The sandy zones are generally characterized by a growth of evergreens	Commonly occupies broad valleys and low depressions between the escarpment formed by the basal sandstone here included in the Judith River formation and that formed by the massive Eagle sandstone	550 ±
				Eagle sandstone	The upper 100 feet consists of moderately soft light-yellow sandstone alternating with beds of sandy shale. The lower 100 feet is massive sandstone	The massive basal sandstone forms a vertical cliff for several miles east of Billings	200
				Colorado shale	The upper 200 or 300 feet exposed in this field is composed of dark marine shale containing scattered calcareous concretions	Is eroded into a deep valley southwest of the prominent Eagle sandstone escarpment	200 or 300 exposed

FORMATIONS EXPOSED IN THE BIRCH CREEK-SUN RIVER AREA, MONT.

Oil and Gas Geology of the Birch Creek-Sun River Area, Northwestern Montana, by Eugene Stebinger. U. S. G. S. Bull. No. 691E

System	Series	Group and formation		Thickness (feet)	Character
Quaternary	Recent	Alluvium			Silt, sand, and gravel, chiefly along stream bottoms
	Pleistocene	Glacial drift		0–150	Boulder clay, gravel, and sand. Contains boulders and cobbles of limestone, sandstone, red quartzite and argillite, and a few granitoid rocks, derived from the mountains
Tertiary	Pleistocene and late Tertiary	Terrace gravels		5–50	Limestone gravels, locally cemented, on terraces and plains at various levels
Tertiary (?)	Eocene (?)	St. Mary River formation		650 +	Clay, clay shale, and soft sandstone, gray to greenish gray
			Horsethief sandstone	250–400	Chiefly massive gray to buff and greenish-gray coarse-grained sandstone with slabby sandstone and shale in lower half. Contains one or more shell beds, mainly of oysters
			Bearpaw shale	0–500	Dark-gray shale with a few thin beds of gray sandstone. Contains marine shells of Pierre types. Present only in northern part of area described. To the south grades into brackish and fresh water clays and sandstones similar to the beds of the Two Medicine formation

Cretaceous	Upper Cretaceous	Montana group	Two Medicine formation	1800–2200	Gray, greenish-gray, and red clay and clay shale with subordinate irregular coarse-grained sandstones, mainly in lower half. Bones of fossil reptiles of Judith River types and fragments of fossil wood are abundant. Thin beds of coal and coaly shale near the base
			Virgelle sandstone	200–380	Upper part, very massive coarse gray sandstone, much cross-bedded and with heavy irregular beds of magnetite sandstone at the top, weathering in deep rusty-red tints. Lower part, interbedded sandstone and shale. Contains gas at Medicine Hat and elsewhere in Alberta and at Havre, Mont.
		Colorado shale with Blackleaf sandy member at base		1800 +	Upper part, dark marine shale with compact bituminous shale and thin maltha-bearing limestones near the base. Lower part, Blackleaf sandy member, coarse sandstones locally conglomeratic in beds 20 to 75 feet thick, alternating with dark marine shale, in part bituminous; thickness 610 to 700 feet
	Lower Cretaceous	Kootenai formation		890–920	Red and green shales and clay shale with many beds of coarse gray sandstones. Contains a few fresh-water shells
Jurassic	Upper Jurassic	Ellis formation		240–310	Black to gray calcareous shale with thin tan-weathering limestone and sandstone. Contains many fossil shells. Marine
		Unconformity			
Carboniferous	Mississippian	Madison and later limestones		1200 +	Massive white to pale-gray fossiliferous limestone, cherty in middle and lower beds; pure coralline limestone in upper beds; bottom not exposed

SECTION OF THE FORMATIONS INVOLVED IN THE HATCHETIGBEE ANTICLINE, ALA.

Oil and Gas Possibiliites of the Hatchetigbee Anticline, Alabama, by O. B. Hopkins.
U. S. G. S. Bull. No. 661H

System	Series	Group	Formation	Thickness in feet	Lithologic character
Quaternary	Recent		Alluvium		Clay, silt, and sand along present streams
	Pleistocene		Alluvial terrace deposits		Sand, gravel, and clay
	Pliocene		Citronelle formation	0–100	Terrace sand and gravel
	Oligocene		Catahoula sandstone	0–200	Light-gray sands, sandstones, and greenish-gray siliceous clays
			"Coral limestone"	0–90	Limestone, hard and soft beds alternating, composed in part largely of corals
		Vicksburg	Marianna limestone	0–90	Limestone, light gray to white, soft, chalky ("chimney rock") below, and hard, semi-crystalline, cavernous (Glendon limestone member, locally termed "horsebone") above
			Red Bluff clay	20–40	Glauconitic clay, marl, and marly limestone below and plastic greenish-gray clay and gypsiferous and in places carbonaceous clay above
			Jackson formation	80–115	Clay, sand, and indurated marl; plastic bluish-green clay at base, followed by medium above fine-grained sand, light-gray indurated marl, and plastic gray or greenish-gray clay at top
			Gosport sand		Greensand and indurated glauconitic sandy marl and subordinate beds of glauconitic clay; replete with shells, especially the greensand

Tertiary	Eocene	Claiborne	Lisbon formation	40–200	Sand, clay, indurated marl, sandstones, and oyster beds; the sands are highly glauconitic and weather red. Almost entirely marine; in large part highly fossiliferous
			Tallahatta buhrstone	20–200	Claystone, sandstone, and argillaceous sandstone, light gray, greenish gray, or green, glauconitic, medium to thin bedded, non-calcareous, highly siliceous, sparingly fossiliferous except in few beds
		Wilcox	Hatchetigbee formation	200–300	Sand, laminated sand, and clay, sandy clay, and plastic clay; these materials are light to dark gray or greenish gray when fresh, but weather to yellow or brown. A large part of the formation is lignitic, but it also contains numerous beds of marine shells
			Bashi formation	80–125	Greensand marl, sandy clay, and beds of lignite; in upper part this formation contains marine shells in abundance and in lower part numerous thin beds of lignite
			Tuscahoma formation	140–200	Sandy clays, sands, and greensands, gray in color and containing several shell beds
			Nanafalia formation	200–250	Clays and sandy clays, indurated and in part glauconitic, followed below by light-gray sands, greensands, and sandy clays; lignite is present at base of formation in some places, and marine shells are abundant in upper part
		Midway	Naheola formation	150–200	Clay and sand beds, alternating; sands are gray and glauconitic and clays are dark gray to black and sandy; marine shells in lower part
			Sucarnochee clay	100–200	Clay, dark brown to black, hard and dense; shells abundant at some places and absent at others
			Clayton limestone	0–25	Limestone, chalky limestone, and hard limestone beds, white to light gray in color, in part clayey and in part sandy. This limestone is absent in some parts of southwestern Alabama

SECTION OF THE FORMATIONS INVOLVED IN THE HATCHETIGBEE ANTICLINE, ALA.—*Cont.*

System	Series	Group	Formation	Thickness in feet	Lithologic character
Cretaceous	Upper Cretaceous		Ripley formation	0–150	Sands, clays, marls, and impure limestones; absent in part of southwestern Alabama, where it merges into Selma chalk; entirely of marine origin
			Selma chalk	900–1000	Chalk, chalky limestone, and thin beds of pure hard limestone; the chalk is grayish white or bluish gray to dark gray, in part clayey and in part sandy
			Eutaw formation	400–500	Sands, laminated sand and clay, and thin beds of lignitic clays; sands are marine, in part massive and in part cross-bedded
			Tuscaloosa formation	300–1000	Sands, clays, and gravels, irregularly bedded, non-marine; contain carbonaceous and lignitic beds in upper part and gravel in the basal part; sands and clays are gray to dark gray or green

GEOLOGIC FORMATIONS IN THE LANDER OIL FIELD, WYOMING

THE LANDER AND SALT CREEK OIL FIELDS, WYOMING, BY E. G. WOODRUFF AND C. H. WEGEMANN.
U. S. G. S. BULL. No. 452

Era	System	Series	Group	Formation	Character	Thickness in feet
Cenozoic	Quaternary	Recent			Alluvium	
	Tertiary	Eocene Unconformity		Wind River formation	Sandy shale, shaly sandstone, and local beds of conglomerate	Only the lower part exposed
Mesozoic	Cretaceous	Upper Cretaceous	Montana	Mesaverde formation	Massive light-buff sandstone and sandy shale	Less than 200 feet exposed
			Colorado	Mancos shale	Drab sandy shale merging upward into moderately rusty very sandy shale	6110
				Dakota sandstone	Massive ferruginous sandstone	20 to 56
		Lower Cretaceous (?)			Shale, sandy, and sandstone in both massive and shaly beds and beds of conglomerate locally developed	400 to 410
	Jurassic (?)			Morrison formation	Variegated sandy shale and conglomerate composed of water-worn pebbles	236 to 242
	Jurassic			Sundance formation	Olive-green fossiliferous limestone and shale	347 to 350
	Triassic (?)			Chugwater formation ("Red Beds")	Sandy shale and massive sandstone	1500
Palozoic	Carboniferous	Pennsylvanian with Permian (?) at top		Embar formation	Massive and shaly limestone (locally containing chert), shale, and sandstone	344

GENERALIZED SECTION OF ROCKS IN THE CLEVELAND GAS FIELD, OHIO

The Cleveland Gas Field, Cuyahoga County, Ohio, with a Study of Rock Pressure, by G. S. Rogers. U. S. G. S. Bull. No. 661A

System	Group or formation		Thickness in feet	Character	Driller's description
Quaternary (Pleistocene series)	Glacial drift		10–400	Boulders, pebbles, sand, and clay	Drift
Carboniferous (Mississippian series)	Berea sandstone		40–150	Medium to coarse grained white, buff, or brown sandstone	Berea grit
Devonian or Carboniferous	Bedford shale		60–80	Bluish-gray to reddish shale, with some thin layers of limestone	Ohio shale, 1100–1400 feet
Devonian	Ohio shale group	Cleveland shale	50–120	Massive hard black bituminous shale with a few bluish layers in lower portion	
		Chagrin shale	850–1200	Soft bluish-gray clay shale, with some concretionary layers	
		Huron shale		Black and bluish shale in upper and lower portions, with a band of gray shale near middle	
	Olentangy (?) shale		80	Gray calcareous shale	

	Delaware limestone	500–700	Blue and gray limestone, becoming dolomitic in lower part. Contains a 30 to 50 foot bed of white quartz sandstone 350 to 450 feet below top	Big lime [includes Newburg sand and some "stray sands in lower 300 feet], 1425–1825 feet
Unconformity	Columbus limestone			
Silurian	Monroe formation			
	Salina formation	400–600	Shale, dolomite, anhydrite or gypsum, and rock salt	
	Niagara limestone	400–600	Dolomite and limestone	
	"Clinton" formation	150–250	Calcareous shale and thin-bedded limestone, with sandstone layer in lower part	[Includes Little lime], 75–150 feet Clinton sand, 0–60 feet 25–75 feet
	"Medina" shale	300–400	Red clay shale with thin layers of sandstone	Medina red rock
Ordovician	Shale and limestone of Cincinnatian age	1100–1250	Dark shale with thin layers of limestone, especially in upper part	Slate and shells
	Trenton (?) limestone	(?)	Limestone	Trenton lime

GENERALIZED SECTION OF FORMATIONS IN THE CORSICANA OIL AND GAS FIELD, TEXAS

The Corsicana Oil and Gas Field, Texas[1] by G. C. Matson and O. B. Hopkins.
U. S. G. S. Bull. No. 661F

System	Series	Group	Formation	Thickness (feet)	Character
Quaternary	Recent				Alluvial deposits along streams
	Pleistocene				Terrace deposits
Tertiary	Eocene		Midway formation	250–500	Micaceous sandy clays, fine argillaceous sands and limestone concretions
	Gulf (Upper Cretaceous)		Navarro formation	1800–2000	Light to dark gray calcareous clay, sandy clay, and fine lenticular beds of sand
			Taylor marl		Massive calcareous clay marl, little or no sand, and glauconite
			Austin chalk	400–500	Gray to white chalky limestone containing some hard beds
			Eagle Ford shale	300–400	Light to dark colored shale or clay and thinly laminated impure limestone
			Woodbine sand	400–450	Sand, sandy lignitic clay, sandstone, ferruginous sand, and clay

Cretaceous	Comanche (Lower Cretaceous)	Washita	Denison formation	150–200	Clay and limestone
			Fort Worth limestone	25–75	Alternating beds of limestone and marl
			Preston formation	50–100	Calcareous laminated clays and impure limestone
		Fredericksburg	Edwards limestone	300–400	White chalky limestones, variously indurated, and in places fine arenaceous beds
			Comanche Peak limestone		
			Walnut clay	100–200	Calcareous clays and impure marly and chalky limestones
		Trinity	Paluxy sand	125–200	Fine-grained sand and lenticular beds of clay
			Glen Rose limestone	300–500	Impure limestone, marl, and calcareous shales
			Travis Peak sand	250 ±	Conglomerate, sand, sandstone, shales, and impure limestones

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[1] The formations below the Navarro formation crop out west of the Corsicana field and dip under it. The Upper Cretaceous formations have been penetrated by the drill in this field and are known from well records; the Lower Cretaceous formations have not been penetrated by the drill in this field but are known from outcrops and well records west of the field. The data relating to the Lower Cretaceous are taken largely from a report by R. T. Hill (Geography and geology of the Black and Grand prairies, Tex.; U. S. Geol. Survey, Twenty-first Ann. Rept., pt. 7, 1901).

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